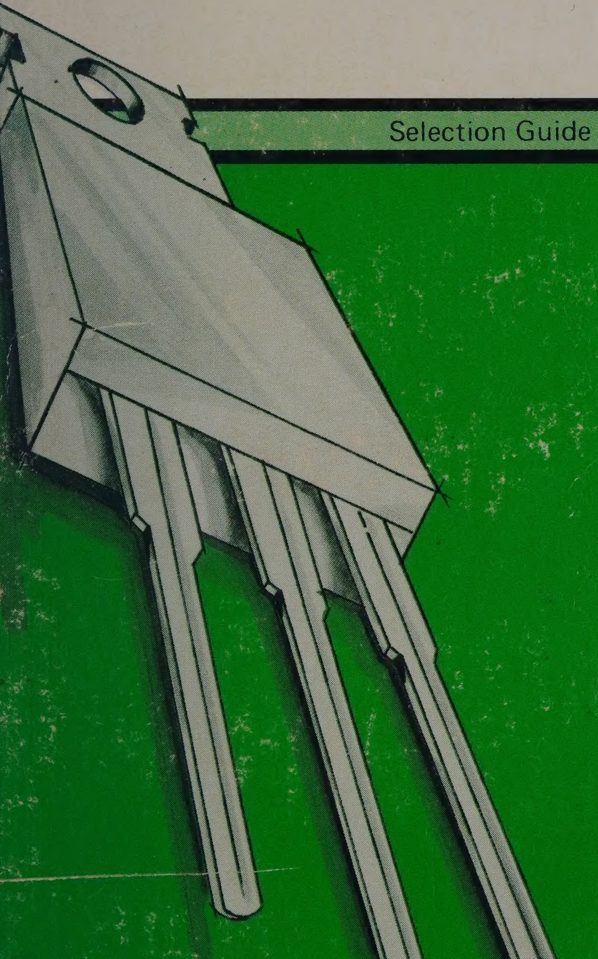
RCA

Thyristors/Rectifiers

Selection Guide / Data / Application Notes



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RCA
Thyristors/Rectifiers

This DATABOOK contains complete data and related application notes on thyristors, rectifiers, and diacs presently available from RCA Solid State Division as standard products. For ease of type selection, product matrix charts and application information are given on pages 12-22. Data sheets are grouped in type-number sequence in the following categories: (a) triacs, (b) silicon controlled rectifiers, (c) rectifiers, (d) diacs. Dimensional outlines and suggested mounting hardware are then shown for all types, followed by application notes in numerical order, and finally by a comprehensive subject index.

To simplify data reference, data sheets in each category are arranged as much as possible in numerical-alphabetical-numerical sequence of type numbers. Because some data sheets include more than one type number, however, some types may be out of sequence. If you don't find the type you're looking for where you expect it to be, please consult the Index to Devices on pages 7-10.

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New solid-state devices and related publications announced during the year are described in a newsletter entitled "What's New in Solid State". If you obtained your DATABOOK(s) directly from RCA, your name is already on the mailing list for this newsletter. If you obtained your book(s) from a source other than RCA and wish to receive the newsletter, please fill out the form on page 4, detach it, and mail it to RCA.

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Because we are interested in your reaction to this approach to data service, we invite you to add your comments to the form when you return it, or to send your remarks to one of the addresses listed at the top of the form. We solicit your constructive criticism to help us improve our service to you.

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Function: (Check One)

- A ☐ Executive/Administration
- B ☐ Purchasing/Procurement
- C ☐ Research/Development
- D ☐ Design Engineer
- E ☐ Application/Components Engineer
- F ☐ Production/Manufacturing
- G ☐ Documentation/Library
- H ☐ Reliability/QA
- I ☐ Education/Training
- J ☐ Program/Project Management
- K ☐ Marketing

Activity: (Check One)

- A ☐ Broadcast
- B ☐ Communication
- C ☐ Instrumentation/Control
- D ☐ Computer/Data Processing
- E ☐ Computer, Peripheral
- F ☐ Automotive
- G ☐ Industrial
- H ☐ Medical
- I ☐ Research
- J ☐ Transportation
- K ☐ Consumer, Electronic
- L ☐ Consumer, Appliance
- M ☐ Space
- N ☐ Ordnance
- O ☐ Avionics
- P ☐ Electronic Warfare

Product Interest: (Indicate order of interest if more than one is marked)

- A ☐ Linear IC's
- B ☐ Digital IC's, COS/MOS
- C ☐ Digital IC's, Bipolar
- D ☐ Thyristors/Rectifiers
- E ☐ Liquid Crystals
- F ☐ Semiconductor Diodes
- G ☐ RF Power Semiconductors
- H ☐ MOSFETS
- I ☐ Power Transistors
- J ☐ Power Hybrid Circuits

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New RCA Type-Numbering System

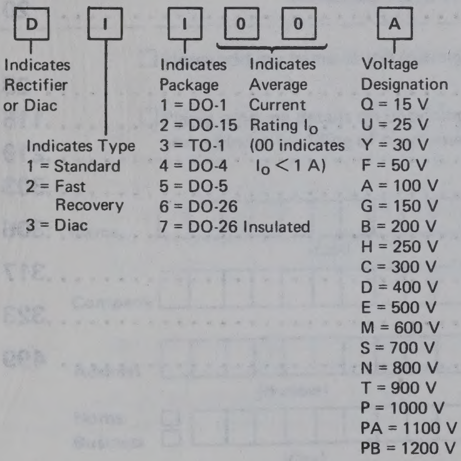
A new system of type numbers has been adopted for all RCA triacs, SCR's, rectifiers, and diacs previously identified by 100-, 40000-, 41000-, 43000-, 44000-, and 45000-series numbers. Type numbers for JEDEC (1N- and 2N-series) devices, which are registered with the Joint Electron Devices Engineering Council of the Electronic Industries Association (EIA), are not affected.

The new type numbers for non-JEDEC RCA thyristors, rectifiers, and diacs consist of an alpha-numeric code that immediately identifies the basic type of device and provides information on significant device features. The basic product type is indicated by the initial letter of the type-number designation; i.e., T = triac, S = SCR, and D = rectifier or diac. The numbers following the initial letter indicate device current ratings, type of package, and electrical variants within a series. The suffix letter(s) define the voltage rating of the device.

Sixteen suffix letters are used to represent specific voltage ratings in the range from 15 to 1000 volts. Combinations of these letters can be used to indicate voltage ratings that differ from the sixteen basic values. (For example, the suffix DF is used for a voltage rating of 450 volts; i.e., D + F = 400 + 50 = 450 volts.)

The charts shown below provide a detailed explanation of the new type number codes. For convenience of type selection, a cross-reference guide that relates "old" type numbers to the new numbers that replace them is provided on page 10.

Graphic Representation of Rectifier and Diac Numbering System



Indicates Rectifier or Diac

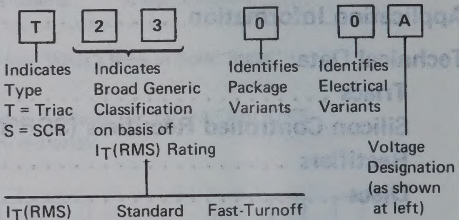
Indicates Type
1 = Standard
2 = Fast Recovery
3 = Diac

Indicates Package
1 = DO-1
2 = DO-15
3 = TO-1
4 = DO-4
5 = DO-5
6 = DO-26
7 = DO-26 Insulated

Indicates Average Current Rating I_o (00 indicates $I_o < 1$ A)

Voltage Designation
Q = 15 V
U = 25 V
Y = 30 V
F = 50 V
A = 100 V
G = 150 V
B = 200 V
H = 250 V
C = 300 V
D = 400 V
E = 500 V
M = 600 V
S = 700 V
N = 800 V
T = 900 V
P = 1000 V
PA = 1100 V
PB = 1200 V

Graphic Representation of Thyristor Numbering System



Indicates Type
T = Triac
S = SCR

Indicates Broad Generic Classification on basis of I_T(RMS) Rating

Identifies Package Variants

Identifies Electrical Variants

Voltage Designation (as shown at left)

I_T(RMS) Ratings (A)	Standard Devices	Fast-Turnoff Devices
0 - 2.5	00 - 09	10 - 19
2.5 - 8	20 - 29	30 - 39
8 - 15	40 - 49	50 - 59
15 - 40	60 - 69	70 - 79
> 40	80 - 89	90 - 99

(NOTE: The first five digits, e.g., T2300, provide the basic device series designation.)

Index to Thyristors, Rectifiers and Diacs

RCA Type No.	Page No.	Type of Device	Current (A)	Voltage (V)	Data Sheet File No.
1N248C	220	Rectifier	20	50	6
1N249C	220	Rectifier	20	100	6
1N250C	220	Rectifier	20	200	6
1N440B	223	Rectifier	0.75	100	5
1N441B	223	Rectifier	0.75	200	5
1N442B	223	Rectifier	0.75	300	5
1N443B	223	Rectifier	0.75	400	5
1N444B	223	Rectifier	0.75	500	5
1N445B	223	Rectifier	0.75	600	5
1N536	225	Rectifier	0.75	50	3
1N537	225	Rectifier	0.75	100	3
1N538	225	Rectifier	0.75	200	3
1N539	225	Rectifier	0.75	300	3
1N540	225	Rectifier	0.75	400	3
1N547	225	Rectifier	0.75	600	3
1N1095	225	Rectifier	0.75	500	3
1N1183A	227	Rectifier	40	50	38
1N1184A	227	Rectifier	40	100	38
1N1186A	227	Rectifier	40	200	38
1N1187A	227	Rectifier	40	300	38
1N1188A	227	Rectifier	40	400	38
1N1189A	227	Rectifier	40	500	38
1N1190A	227	Rectifier	40	600	38
1N1195A	220	Rectifier	20	300	6
1N1196A	220	Rectifier	20	400	6
1N1197A	220	Rectifier	20	500	6
1N1198A	220	Rectifier	20	600	6
1N1199A	230	Rectifier	12	50	20
1N1200A	230	Rectifier	12	100	20
1N1202A	230	Rectifier	12	200	20
1N1203A	230	Rectifier	12	300	20
1N1204A	230	Rectifier	12	400	20
1N1205A	230	Rectifier	12	500	20
1N1206A	230	Rectifier	12	600	20
1N1341B	233	Rectifier	6	50	58
1N1342B	233	Rectifier	6	100	58
1N1344B	233	Rectifier	6	200	58
1N1345B	233	Rectifier	6	300	58
1N1346B	233	Rectifier	6	400	58
1N1347B	233	Rectifier	6	500	58
1N1348B	233	Rectifier	6	600	58
1N1763A	234	Rectifier	1	400	89
1N1764A	234	Rectifier	1	500	89
1N2858A	240	Rectifier	1	50	91
1N2859A	240	Rectifier	1	100	91
1N2860A	240	Rectifier	1	200	91
1N2861A	240	Rectifier	1	300	91
1N2862A	240	Rectifier	1	400	91
1N2863A	240	Rectifier	1	500	91
1N2864A	240	Rectifier	1	600	91
1N3193	244	Rectifier	0.75	200	41
1N3194	244	Rectifier	0.75	400	41
1N3195	244	Rectifier	0.75	600	41
1N3196	244	Rectifier	0.5	800	41
1N3253	244	Rectifier	0.75	200	41
1N3254	244	Rectifier	0.75	400	41
1N3255	244	Rectifier	0.75	600	41
1N3256	244	Rectifier	0.5	800	41
1N3563	244	Rectifier	0.4	1000	41
1N3879	247	Rectifier	6	50	726
1N3880	247	Rectifier	6	100	726
1N3881	247	Rectifier	6	200	726
1N3882	247	Rectifier	6	300	726
1N3883	247	Rectifier	6	400	726
1N3889	249	Rectifier	12	50	727
1N3890	249	Rectifier	12	100	727
1N3891	249	Rectifier	12	200	727
1N3892	249	Rectifier	12	300	727
1N3893	249	Rectifier	12	400	727
1N3899	251	Rectifier	20	50	728
1N3900	251	Rectifier	20	100	728
1N3901	251	Rectifier	20	200	728
1N3902	251	Rectifier	20	300	728
1N3903	251	Rectifier	20	400	728
1N3909	253	Rectifier	30	50	729
1N3910	253	Rectifier	30	100	729
1N3911	253	Rectifier	30	200	729
1N3912	253	Rectifier	30	300	729
1N3913	253	Rectifier	30	400	729
1N5211	255	Rectifier	1	200	245
1N5212	255	Rectifier	1	400	245
1N5213	255	Rectifier	1	600	245
1N5214	255	Rectifier	0.75	800	245
1N5215	255	Rectifier	1	200	245
1N5216	255	Rectifier	1	400	245
1N5217	255	Rectifier	1	600	245
1N5218	255	Rectifier	0.75	800	245
1N5391	257	Rectifier	1.5	50	478
1N5392	257	Rectifier	1.5	100	478
1N5393	257	Rectifier	1.5	200	478
1N5394	257	Rectifier	1.5	300	478
1N5395	257	Rectifier	1.5	400	478
1N5396	257	Rectifier	1.5	500	478
1N5397	257	Rectifier	1.5	600	478
1N5398	257	Rectifier	1.5	800	478
1N5399	257	Rectifier	1.5	1000	478
2N681	116	SCR	25	25	96
2N682	116	SCR	25	50	96
2N683	116	SCR	25	100	96
2N684	116	SCR	25	150	96
2N685	116	SCR	25	200	96
2N686	116	SCR	25	250	96
2N687	116	SCR	25	300	96
2N688	116	SCR	25	400	96
2N689	116	SCR	25	500	96
2N690	116	SCR	25	600	96
2N1842A	119	SCR	16	25	28
2N1843A	119	SCR	16	50	28
2N1844A	119	SCR	16	100	28
2N1845A	119	SCR	16	150	28
2N1846A	119	SCR	16	200	28
2N1847A	119	SCR	16	250	28
2N1848A	119	SCR	16	300	28
2N1849A	119	SCR	16	400	28
2N1850A	119	SCR	16	500	28
2N3228	123	SCR	5	200	114
2N3525	123	SCR	5	400	114
2N3528	123	SCR	2	200	114
2N3529	123	SCR	2	400	114
2N3650	129	SCR	35	100	408
2N3651	129	SCR	35	200	408
2N3652	129	SCR	35	300	408
2N3653	129	SCR	35	400	408
2N3654	135	SCR	35	50	724
2N3655	135	SCR	35	100	724
2N3656	135	SCR	35	200	724
2N3657	135	SCR	35	300	724
2N3658	135	SCR	35	400	724
2N3668	141	SCR	12.5	100	116
2N3669	141	SCR	12.5	200	116
2N3670	141	SCR	12.5	400	116
2N3870	147	SCR	35	100	578
2N3871	147	SCR	35	200	578
2N3872	147	SCR	35	400	578
2N3873	147	SCR	35	600	578
2N3896	147	SCR	35	100	578
2N3897	147	SCR	35	200	578
2N3898	147	SCR	35	400	578
2N3899	147	SCR	35	600	578
2N4101	123	SCR	5	600	114
2N4102	123	SCR	2	600	114
2N4103	141	SCR	12.5	600	116
2N5441	24	Triac	40	200	593
2N5442	24	Triac	40	400	593
2N5443	24	Triac	40	600	593
2N5444	24	Triac	40	200	593
2N5445	24	Triac	40	400	593
2N5446	24	Triac	40	600	593
2N5567	29	Triac	10	200	457
2N5568	29	Triac	10	400	457

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RCA Type No.	Page No.	Type of Device	Current (A)	Voltage (V)	Data Sheet File No.
2N5569	29	Triac	10	200	457
2N5570	29	Triac	10	400	457
2N5571	34	Triac	15	200	458
2N5572	34	Triac	15	400	458
2N5573	34	Triac	15	200	458
2N5574	34	Triac	15	400	458
2N5754	39	Triac	2.5	100	414
2N5755	39	Triac	2.5	200	414
2N5756	39	Triac	2.5	400	414
2N5757	39	Triac	2.5	600	414
D1201A	260	Rectifier	1	100	495
D1201B	260	Rectifier	1	200	495
D1201D	260	Rectifier	1	400	495
D1201F	260	Rectifier	1	50	495
D1201M	260	Rectifier	1	600	495
D1201N	260	Rectifier	1	800	495
D1201P	260	Rectifier	1	1000	495
D1300A	263	Rectifer	0.25	100	784
D1300B	263	Rectifer	0.25	200	784
D1300D	263	Rectifer	0.25	400	784
D2101S	265	Rectifier	1	700	522
D2103S	265	Rectifier	3	700	522
D2103SF	265	Rectifier	3	750	522
D2201A	271	Rectifier	1	100	629
D2201B	271	Rectifier	1	200	629
D2201D	271	Rectifier	1	400	629
D2201F	271	Rectifier	1	50	629
D2201M	271	Rectifier	1	600	629
D2201N	271	Rectifier	1	800	629
D2406A	275	Rectifier	6	100	663
D2406B	275	Rectifier	6	200	663
D2406C	275	Rectifier	6	300	663
D2406D	275	Rectifier	6	400	663
D2406F	275	Rectifier	6	50	663
D2406M	275	Rectifier	6	600	663
D2412A	279	Rectifier	12	100	664
D2412B	279	Rectifier	12	200	664
D2412C	279	Rectifier	12	300	664
D2412D	279	Rectifier	12	400	664
D2412F	279	Rectifier	12	50	664
D2412M	279	Rectifier	12	600	664
D2520A	283	Rectifier	20	100	665
D2520B	283	Rectifier	20	200	665
D2520C	283	Rectifier	20	300	665
D2520D	283	Rectifier	20	400	665
D2520F	283	Rectifier	20	50	665
D2520M	283	Rectifier	20	600	665
D2540A	287	Rectifier	40	100	580
D2540B	287	Rectifier	40	200	580
D2540D	287	Rectifier	40	400	580
D2540F	287	Rectifier	40	50	580
D2540M	287	Rectifier	40	600	580
D2600M	291	Rectifier	0.5	600	839
D2601A	297	Rectifier	1	100	723
D2601B	297	Rectifier	1	200	723
D2601D	297	Rectifier	1	400	723
D2601E	291	Rectifier	1	500	839
D2601F	297	Rectifier	1	50	723
D2601M	291	Rectifier	1	600	723
D2601N	291	Rectifier	1	800	723
D3202U	304	Diac	2 (pk)	25-40	577
D3202Y	304	Diac	2 (pk)	29-35	577
S2060A	152	SCR	4	100	654
S2060B	152	SCR	4	200	654
S2060C	152	SCR	4	300	654
S2060D	152	SCR	4	400	654
S2060E	152	SCR	4	500	654
S2060F	152	SCR	4	50	654
S2060M	152	SCR	4	600	654
S2060Q	152	SCR	4	15	654
S2060Y	152	SCR	4	30	654
S2061A	152	SCR	4	100	654
S2061B	152	SCR	4	200	654
S2061C	152	SCR	4	300	654
S2061D	152	SCR	4	400	654
S2061E	152	SCR	4	500	654
S2061F	152	SCR	4	50	654
S2061M	152	SCR	4	600	654
S2061Q	152	SCR	4	15	654
S2061Y	152	SCR	4	30	654
S2062A	152	SCR	4	100	654
S2062B	152	SCR	4	200	654
S2062C	152	SCR	4	300	654
S2062D	152	SCR	4	400	654
S2062E	152	SCR	4	500	654
S2062F	152	SCR	4	50	654
S2062M	152	SCR	4	600	654
S2062Q	152	SCR	4	15	654
S2062Y	152	SCR	4	30	654
S2400A	157	SCR	4.5	100	567
S2400B	157	SCR	4.5	200	567
S2400D	157	SCR	4.5	400	567
S2400M	157	SCR	4.5	600	567
S2600B	162	SCR	7	200	496
S2600D	162	SCR	7	400	496
S2600M	162	SCR	7	600	496
S2610B	162	SCR	3.3	200	496
S2610D	162	SCR	3.3	400	496
S2610M	162	SCR	3.3	600	496
S2620B	162	SCR	7	200	496
S2620D	162	SCR	7	400	496
S2620M	162	SCR	7	600	496
S2710B	168	SCR	1.7	200	266
S2710D	168	SCR	1.7	400	266
S2710M	168	SCR	1.7	600	266
S2800A	169	SCR	8	100	501
S2800B	169	SCR	8	200	501
S2800D	169	SCR	8	400	501
S3700B	174	SCR	5	200	306
S3700D	174	SCR	5	400	306
S3700M	174	SCR	5	600	306
S3701M	181	SCR	5	600	476
S3702S	183	SCR	5	700	522
S3703SF	183	SCR	5	750	522
S3704A	189	SCR	5	100	690
S3704B	189	SCR	5	200	690
S3704D	189	SCR	5	400	690
S3704M	189	SCR	5	600	690
S3704S	189	SCR	5	700	690
S3705M	195	SCR	5	600	839
S3706E	195	SCR	5	500	839
S3714A	189	SCR	5	100	690
S3714B	189	SCR	5	200	690
S3714D	189	SCR	5	400	690
S3714M	189	SCR	5	600	690
S3714S	189	SCR	5	700	690
S3800D	201	ITR*	5	400	639
S3800E	201	ITR*	5	500	639
S3800EF	201	ITR*	5	550	639
S3800M	201	ITR*	5	600	639
S3800MF	201	ITR*	5	650	639
S3800S	201	ITR*	5	700	639
S3800SF	201	ITR*	5	750	639
S5210B	204	SCR	10	200	757
S5210D	204	SCR	10	400	757
S5210M	204	SCR	10	600	757
S6200A	208	SCR	20	100	418
S6200B	208	SCR	20	200	418
S6200D	208	SCR	20	400	418
S6200M	208	SCR	20	600	418
S6210A	208	SCR	20	100	418
S6210B	208	SCR	20	200	418
S6210D	208	SCR	20	400	418
S6210M	208	SCR	20	600	418
S6220A	208	SCR	20	100	418
S6220B	208	SCR	20	200	418
S6220D	208	SCR	20	400	418
S6220M	208	SCR	20	600	418
S6400N	147	SCR	35	800	578
S6410N	147	SCR	35	800	578
S6420A	147	SCR	35	100	578
S6420B	147	SCR	35	200	578
S6420D	147	SCR	35	400	578
S6420M	147	SCR	35	600	578
S6420N	147	SCR	35	800	578

*Integrated thyristor and rectifier.

Index to Thyristors, Rectifiers and Diacs (cont'd)

RCA Type No.	Page No.	Type of Device	Current (A)	Voltage (V)	Data Sheet File No.
S6431M	213	SCR	35	600	247
S7430M	129	SCR	35	600	408
S7432M	135	SCR	35	600	724
T2300A	44	Triac	2.5	100	470
T2300B	44	Triac	2.5	200	470
T2300D	44	Triac	2.5	400	470
T2301A	51	Triac	2.5	100	431
T2301B	51	Triac	2.5	200	431
T2301D	51	Triac	2.5	400	431
T2302A	44	Triac	2.5	100	470
T2302B	44	Triac	2.5	200	470
T2302D	44	Triac	2.5	400	470
T2304B	52	Triac	0.5	200	441
T2304D	52	Triac	0.5	400	441
T2305B	52	Triac	0.5	200	441
T2305D	52	Triac	0.5	400	441
T2306A	57	Triac	2.5	100	406
T2306B	57	Triac	2.5	200	406
T2306D	57	Triac	2.5	400	406
T2310A	44	Triac	1.6	470	470
T2310B	44	Triac	1.6	200	470
T2310D	44	Triac	1.6	400	470
T2311A	51	Triac	1.6	100	431
T2311B	51	Triac	1.6	200	431
T2311D	51	Triac	1.6	400	431
T2312A	41	Triac	1.9	100	470
T2312B	41	Triac	1.9	200	470
T2312D	41	Triac	1.9	400	470
T2313A	39	Triac	1.9	100	414
T2313B	39	Triac	1.9	200	414
T2313D	39	Triac	1.9	400	414
T2313M	39	Triac	1.9	600	414
T2316A	57	Triac	2.5	100	406
T2316B	57	Triac	2.5	200	406
T2316D	57	Triac	2.5	400	406
T2500B	59	Triac	6	200	615
T2500D	59	Triac	6	400	615
T2700B	64	Triac	6	200	351
T2700D	64	Triac	6	400	351
T2706B	57	Triac	6	200	406
T2706D	57	Triac	6	400	406
T2710B	64	Triac	3.3	200	351
T2710D	64	Triac	3.3	400	351
T2716B	57	Triac	3.3	200	406
T2716D	57	Triac	3.3	400	406
T2800B	69	Triac	8	200	838
T2800C	69	Triac	8	300	838
T2800D	69	Triac	8	400	838
T2800E	69	Triac	8	500	838
T2800M	69	Triac	8	600	838
T2801B	74	Triac	6	200	837
T2801C	74	Triac	6	300	837
T2801D	74	Triac	6	400	837
T2801E	74	Triac	6	500	837
T2802B	69	Triac	8	200	838
T2802C	69	Triac	8	300	838
T2802D	69	Triac	8	400	838
T2802E	69	Triac	8	500	838
T2802M	69	Triac	8	600	838
T2806B	57	Triac	8	200	406
T2806D	57	Triac	8	400	406
T2850A	79	Triac	8	100	540
T2850B	79	Triac	8	200	540
T2850D	79	Triac	8	400	540
T4100M	34	Triac	15	600	458
T4101M	29	Triac	10	600	457
T4103B	84	Triac	15	200	443
T4103D	84	Triac	15	400	443
T4104B	84	Triac	10	200	443
T4104D	84	Triac	10	400	443
T4105B	84	Triac	6	200	443
T4105D	84	Triac	6	400	443
T4106B	57	Triac	15	200	406
T4106D	57	Triac	15	400	406
T4107B	57	Triac	10	200	406
T4107D	57	Triac	10	400	406
T4110M	34	Triac	15	600	458
T4111M	29	Triac	10	600	457
T4113B	84	Triac	15	200	443
T4113D	84	Triac	15	400	443
T4114B	84	Triac	10	200	443
T4114D	84	Triac	10	400	443
T4115B	84	Triac	6	200	443
T4115D	84	Triac	6	400	443
T4116B	57	Triac	15	200	406
T4116D	57	Triac	15	400	406
T4117B	57	Triac	10	200	406
T4117D	57	Triac	10	400	406
T4120B	34	Triac	15	200	458
T4120D	34	Triac	15	400	458
T4120M	34	Triac	15	600	458
T4121B	29	Triac	10	200	457
T4121D	29	Triac	10	400	457
T4121M	29	Triac	10	600	457
T4700B	89	Triac	15	200	300
T4700D	89	Triac	15	400	300
T4706B	57	Triac	15	200	406
T4706D	57	Triac	15	400	406
T6400N	24	Triac	40	800	593
T6401B	94	Triac	30	200	459
T6401D	94	Triac	30	400	459
T6401M	94	Triac	30	600	459
T6404B	99	Triac	40	200	487
T6404D	99	Triac	40	400	487
T6405B	99	Triac	25	200	487
T6405D	99	Triac	25	400	487
T6406B	57	Triac	40	200	406
T6406D	57	Triac	40	400	406
T6406M	57	Triac	40	600	406
T6407B	57	Triac	30	200	406
T6407D	57	Triac	30	400	406
T6407M	57	Triac	30	600	406
T6410N	24	Triac	40	800	593
T6411B	94	Triac	30	200	459
T6411D	94	Triac	30	400	459
T6411M	94	Triac	30	600	459
T6414B	99	Triac	40	200	487
T6414D	99	Triac	40	400	487
T6415B	99	Triac	25	200	487
T6415D	99	Triac	25	400	487
T6416B	57	Triac	40	200	406
T6416D	57	Triac	40	400	406
T6416M	57	Triac	40	600	406
T6417B	57	Triac	30	200	406
T6417D	57	Triac	30	400	406
T6417M	57	Triac	30	600	406
T6420B	24	Triac	40	200	593
T6420D	24	Triac	40	400	593
T6420M	24	Triac	40	600	593
T6420N	24	Triac	40	800	593
T6421B	94	Triac	30	200	459
T6421D	94	Triac	30	400	459
T6421M	94	Triac	30	600	459
T8401B	104	Triac	60	200	725
T8401D	104	Triac	60	400	725
T8401M	104	Triac	60	600	725
T8411B	104	Triac	60	200	725
T8411D	104	Triac	60	400	725
T8411M	104	Triac	60	600	725
T8421B	104	Triac	60	200	725
T8421D	104	Triac	60	400	725
T8421M	104	Triac	60	600	725
T8430B	109	Triac	80	200	549
T8430D	109	Triac	80	400	549
T8430M	109	Triac	80	600	549
T8440B	109	Triac	80	200	549
T8440D	109	Triac	80	400	549
T8440M	109	Triac	80	600	549
T8450B	109	Triac	80	200	549
T8450D	109	Triac	80	400	549
T8450M	109	Triac	80	600	549

RCA Thyristors/Rectifiers Type-Number Cross-Reference Guide

(Old numbers to NEW numbers)

Former RCA Type No.	NEW RCA Type No.
RCA106A	S2060A
RCA106B	S2060B
RCA106C	S2060C
RCA106D	S2060D
RCA106E	S2060E
RCA106F	S2060F
RCA106Q	S2060Q
RCA106M	S2060M
RCA106Y	S2060Y
RCA107A	S2061A
RCA107B	S2061B
RCA107C	S2061C
RCA107D	S2061D
RCA107E	S2061E
RCA107F	S2061F
RCA107Q	S2061Q
RCA107M	S2061M
RCA107Y	S2061Y
RCA108A	S2062A
RCA108B	S2062B
RCA108C	S2062C
RCA108D	S2062D
RCA108E	S2062E
RCA108F	S2062F
RCA108Q	S2062Q
RCA108M	S2062M
RCA108Y	S2062Y
40216	S6431M
40429	T2700B
40430	T2700D
40502	T2710B
40503	T2710D
40504	S2710B
40505	S2710D
40506	S2710M
40525	T2300A
40526	T2300B
40527	T2300D
40528	T2302A
40529	T2302B
40530	T2302D
40531	T2310A
40532	T2310B
40533	T2310D
40534	T2312A
40535	T2312B
40536	T2312D
40553	S3700B
40554	S3700D
40555	S3700M
40575	T4700B
40576	T4700D
40654	S2600B
40655	S2600D
40656	S2620B
40657	S2620D
40658	S2610B
40659	S2610D
40660	T6401B
40661	T6401D
40662	T6411B
40663	T6411D
40668	T2800B
40669	T2800D
40670	T2800M
40671	T6401M
40672	T6411M
40680	S6420A
40681	S6420B
40682	S6420D
40683	S6420M
40684	T2313A
40685	T2313B
40686	T2313D
40687	T2313M
40688	T6420B
40689	T6420D
40690	T6420M
40691	T2301B
40692	T2301D
40693	T2316A
40694	T2316B
40695	T2316D
40696	T2306A
40697	T2306B
40698	T2306D
40699	T6406B
40700	T6406D
40701	T6406M
40702	T6416B
40703	T6416D
40704	T6416M
40705	T6407B
40706	T6407D
40707	T6417B
40708	T6417D
40709	T6407M
40710	T6417M
40711	T4106B
40712	T4106D
40713	T4116B
40714	T4116D
40715	T4706B
40716	T4706D
40717	T4107B
40718	T4107D
40719	T4117B
40720	T4117D
40721	T2806B
40722	T2806D
40727	T2706B
40728	T2706D
40729	T2716B
40730	T2716D
40735	S7430M
40749	S6200A
40750	S6200B
40751	S6200D
40752	S6200M
40753	S6210A
40754	S6210B
40755	S6210D
40756	S6210M
40757	S6220A
40758	S6220B
40759	S6220D
40760	S6220M
40761	T2311B
40762	T2311D
40766	T2301A
40767	T2311A
40768	S3701M
40769	T2304B
40770	T2304D
40771	T2305B
40772	T2305D
40775	T4105B
40776	T4105D
40777	T4115B
40778	T4115D
40779	T4104B
40780	T4104D
40781	T4114B
40782	T4114D
40783	T4103B
40784	T4103D
40785	T4113B
40786	T4113D
40787	T6405B
40788	T6405D
40789	T6415B
40790	T6415D
40791	T6404B
40792	T6404D
40793	T6414B
40794	T6414D
40795	T4101M
40796	T4111M
40797	T4100M
40798	T4110M
40799	T4121B
40800	T4121D
40801	T4121M
40802	T4120B
40803	T4120D
40804	T4120M
40805	T6421B
40806	T6421D
40807	T6421M
40833	S2600M
40834	S2620M
40835	S2610M
40867	S2800A
40868	S2800B
40869	S2800D
40888	S3703SF
40889	S3702S
40890	D2103SF
40891	D2103S
40892	D2101S
40900	T2850A
40901	T2850B
40902	T2850D
40916	T8430B
40917	T8430D
40918	T8430M
40919	T8440B
40920	T8440D
40921	T8440M
40922	T8450B
40923	T8450D
40924	T8450M
40925	T6400N
40926	T6410N
40927	T6420N
40937	S6400N
40938	S6410N
40942	S2400A
40943	S2400B
40944	S2400D
40945	S2400M
40952	S6420N
40956	D2540F
40957	D2540A
40958	D2540B
40959	D2540D
40960	D2540M
41014	T2500B
41015	T2500D
41017	S3800SF
41018	S3800MF
41019	S3800E
41020	S3800S
41021	S3800M
41022	S3800EF
41023	S3800D
41029	T8401B
41030	T8401D
41031	T8401M
41032	T8411B
41033	T8411D
41034	T8411M
41035	T8421B
41036	T8421D
41037	T8421M
43879	D2406F
43880	D2406A
43881	D2406B
43882	D2406C
43883	D2406D
43884	D2406M
43889	D2412F
43890	D2412A
43891	D2412B
43892	D2412C
43893	D2412D
43894	D2412M
43899	D2520F
43900	D2520A
43901	D2520B
43902	D2520C
43903	D2520D
43904	D2520M
44001	D1201F
44002	D1201A
44003	D1201B
44004	D1201D
44005	D1201M
44006	D1201N
44007	D1201P
44933	D2201F
44934	D2201A
44935	D2201B
44936	D2201D
44937	D2201M
44938	D2201N
45411	D3202Y
45412	D3202U
TA7892	D2601B
TA7893	D2601D
TA7894	D2601M
TA7895	D2601N

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Triac Product Matrix

RCA Triacs			Modified TO-5				Modified TO-5 With Heat Radiator				TO-66	
STANDARD	$I_{T(RMS)}$		2.5A	2.5A	2.5A	2.5A	2.5A	2.5A	2.5A	2.5A	6.0A	15.0A
	I_{TSM}		25A	25A	25A	25A	25A	25A	25A	25A	100A	100A
	V_{DROM}(V)	100	T2300A	T2301A	T2302A	2N5754	T2310A	T2311A	T2312A	T2313A		
		200	T2300B	T2301B	T2302B	2N5755	T2310B	T2311B	T2312B	T2313B	T2700B	T4700B
		400	T2300D	T2301D	T2302D	2N5756	T2310D	T2311D	T2312D	T2313D	T2700D	T4700D
		500										
		600				2N5757				T2313M		
		800										
	I_{GT}(mA)	1+, 111−	3	4	10	25	3	4	10	25	25	
		1−, 111+	3	4	10	40	3	4	10	40	40	
	V_{GT}(V)	All Modes	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	
		File No.	470	431	470	414	470	431	470	414	351	
ZERO VOLTAGE SWITCH	V_{DROM}(V)	100				T2306A				T2316A		
		200				T2306B				T2316B	T2706B	T4706B
		400				T2306D				T2316D	T2706D	T4706D
		500										
		600										
	I_{GT}(mA)	1+, 111 −				45				45	45	45
	V_{GT}(V)	1+, 111+				1.5				1.5	1.5	1.5
		File No.				406				406	406	406
400-HZ OPERATION	$I_{T(RMS)}$				0.5A	0.5A						
	V_{DROM}(V)	200			T2304B	T2305B						
		400			T2304D	T2305D						
	I_{GT}(mA)	1+, 111−			10	25						
		1−, 111+			10	40						
	V_{GT}(V)	All Modes			2.2	2.2						
		File No.			441	441						

Triac Product Matrix (cont'd)

RCA Triacs			TO-66 With Heat Radiator	TO-220AB VERSAWATT					Press Fit		
STANDARD	I_T(RMS)		6.0A	6A	6A	8.0A	8A	ISOWATT 8A		10.0A	15.0A
	I_{TSM}		100A	60A	80A	100A	100A	100A		100A	100A
	V_{DROM}(V)	100						T2850A			
		200	T2710B	T2500B	T2801B	T2800B	T2802B	T2850B		2N5567	2N5571
		300			T2801C	T2800C	T2802C				
		400	T2710D	T2500D	T2801D	T2800D	T2802D	T2850D		2N5568	2N5572
		500			T2801E	T2800E	T2802E				
		600				T2800M	T2802M			T4101M	T4100M
		800									
	I_{GT}(mA)	1+, 111−	25	25	80	25	50	25		25	50
		1−, 111+	40	60	–	60	–	60		40	80
	V_{GT}(V)	All Modes	2.2	2.5	4.0▲	2.5	2.5▲	2.5		2.5	2.5
		File No.	351	615	837	838	838	540		457	458
ZERO VOLTAGE SWITCH	V_{DROM}(V)	100									
		200	T2716B			T2806B				T4107B	T4106B
		400	T2716D			T2806D				T4107D	T4106D
		500									
		600									
	I_{GT}(mA)	1+, 111−	45			45				45	45
	V_{GT}(V)	1+, 111+	1.5			1.5				1.5	1.5
		File No.	406			406				406	406
400-HZ OPERATION	I_T(RMS)								6A	10.A	15.0A
	V_{DROM}(V)	200							T4105B	T4104B	T4103B
		400							T4105D	T4104D	T4103D
	I_{GT}(mA)	1+, 111−							50	50	50
		1−, 111+							80	80	80
	V_{GT}(V)	All Modes							2.5	2.5	2.5
		File No.							443	443	443

* ISOWATT — Mounting tab electrically isolated from electrodes.

▲1+, 111− only.

Triac Product Matrix (cont'd)

RCA Triacs			Stud			Isolated Stud		Press Fit		Stud	
STANDARD	I_T(RMS)			10.0A	15.0A	10.0A	15.0A	30.0A	40.0A	30.0A	40.0A
	I_{TSM}			100A	100A	100A	100A	300A	300A	300A	300A
	V_{DROM}(V)	100									
		200		2N5569	2N5573	T4121B	T4120B	T6401B	2N5441	T6411B	2N5444
		400		2N5570	2N5574	T4121D	T4120D	T6401D	2N5442	T6411D	2N5445
		500									
		600		T4111M	T4110M	T4121M	T4120M	T6401M	2N5443	T6411M	2N5446
		800							T6400N		T6410N
	I_{GT}(mA)	I+, III−		25	50	25	50	50	50	50	50
		I−, III		40	80	40	80	80	80	80	80
	V_{GT}(V)	All Modes		2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
		File No.		457	458	457	458	459	593	459	593
ZERO VOLTAGE SWITCH	V_{DROM}(V)	100									
		200		T4117B	T4116B			T6407B	T6406B	T6417B	T6416B
		400		T4117D	T4116D			T6407D	T6406D	T6417D	T6416D
		500									
		600						T6407M	T6406M	T6417M	T6416M
	I_{GT}(mA)	I+, III−		45	45			45	45	45	45
	V_{GT}(V)	I+, III+		1.5	1.5			1.5	1.5	1.5	1.5
		File No.		406	406			406	406	406	406
400-HZ OPERATION	I_T(RMS)		6A	10.0A	15.0A			25.0A	40.0A	25.0A	40.0A
	V_{DROM}(V)	200	T4115B	T4114B	T4113B			T6405B	T6404B	T6415B	T6414B
		400	T4115D	T4114D	T4113D			T6405D	T6404D	T6415D	T6414D
	I_{GT}(mA)	I+, III−	50	50	50			80	80	80	80
		I−, III+	80	80	80			120	120	120	120
	V_{GT}(V)	All Modes	2.5	2.5	2.5			3.0	3.0	3.0	3.0
		File No.	443	443	443			487	487	487	487

Triac Product Matrix (cont'd)

RCA Triacs			Isolated Stud		Press Fit*		Stud*		Isolated Stud*	
STANDARD	I_T(RMS)		30.0A	40.0A	60A	80A	60A	80A	60A	80A
	I_{TSM}		300A	300A	600A	850A	600A	850A	600A	850A
	V_{DROM}(V)	100								
		200	T6421B	T6420B	T8401B	T8430B	T8411B	T8440B	T8421B	T8450B
		400	T6421D	T6420D	T8401D	T8430D	T8411D	T8440D	T8421D	T8450D
		500								
		600	T6421M	T6420M	T8401M	T8430M	T8411M	T8440M	T8421M	T8450M
		800		T6420N						
	I_{GT}(mA)	1+, 111–	50	50	75	75	75	75	75	75
		1–, 111+	80	80	150	150	150	150	150	150
	V_{GT}(V)	All Modes	2.5	2.5	2.8	2.5	2.8	2.5	2.8	2.5
		File No.	459	593	725	549	725	549	725	549
ZERO VOLTAGE SWITCH	V_{DROM}(V)	100								
		200								
		400								
		500								
		600								
	I_{GT}(mA)	1+, 111–								
	V_{GT}(V)	1+, 111+								
		File No.								
400-HZ OPERATION	I_T(RMS)									
	V_{DROM}(V)	200								
		400								
	I_{GT}(mA)	1+, 111–								
		1–, 111+								
	V_{GT}(V)	All Modes								
		File No.								

* Package has factory-attached flexible leads for main terminals 1 and 2.

SCR Product Matrix

RCA SCR's		TO-8		TO-66						
$I_{T(RMS)}$		2.0A	4.5A	5.0A	FTO 5.0A	FTO 5.0A	FTO 5A	FTO 5.0A	FTO 5.0A	FTO 5.0A
I_{TSM}		60A	200A	60A	80A	80A	80A	75A(I_{PM})	50A	50A
V_{DROM}	15									
V_{RROM}(V)	25									
	30									
	50									
	100		S2400A				S3704A			
	150									
	200	2N3528	S2400B	2N3228		S3700B	S3704B			
	250									
	300									
	400	2N3529	S2400D	2N3525		S3700D	S3704D			
	500				S3706E					
	600	2N4102	S2400M	2N4101	S3705M	S3700M	S3704M	S3701M		
	700						S3704S		S3702S	
	750									S3703SF
	800									
I_{GT}(mA)		15	15	15	30	40	40	35	45	40
V_{GT}(V)		2	2	2	4	3.5	3.5	4	4	4
	File No.	114	567	114	839	306	690	476	522	522

RCA SCR'S		TO-66 With Heat Rad		Low Profile Mod. TO-5	TO-5 With Heat Rad.	TO-5 With Heat Spreader	TO-220AB VERSAWATT			
$I_{T(RMS)}$		5.0A	FTO 5A	7.0A	3.3A	7.0A	4.0A	4.0A	4A	8.0A
I_{TSM}		60A	80A	100A	100A	100A	35A	35A	35A	100A
V_{DROM}	15						S2060Q	S2061Q	S2062Q	
V_{RROM}(V)	25									
	30						S2060Y	S2061Y	S2062Y	
	50						S2060F	S2061F	S2062F	
	100		S3714A				S2060A	S2061A	S2062A	S2800A
	150									
	200	S2710B	S3714B	S2600B	S2610B	S2620B	S2060B	S2061B	S2062B	S2800B
	250									
	300						S2060C	S2061C	S2062C	
	400	S2710D	S3714D	S2600D	S2610D	S2620D	S2060D	S2061D	S2062D	S2800D
	500						S2060E	S2061E	S2062E	
	600	S2710M	S3714M	S2600M	S2610M	S2620M	S2060M	S2061M	S2062M	
	700		S3714S							
	750									
	800									
I_{GT}(mA)		15	40	15	15	15	0.2	0.5	2	15
V_{GT}(V)		2	3.5	1.5	1.5	1.5	0.8	0.8	0.8	1.5
	File No.	266	690	496	496	496	654	654	654	501

FTO — Fast Turn-Off

SCR Product Matrix (cont'd)

RCA SCR's		Stud	TO-3	Press Fit		Stud		Isolated Stud	
$I_{T(RMS)}$		10A	12.5A	20.0A	35.0A	20.0A	35.0A	20.0A	35.0A
I_{TSM}		90A	200A	200A	350A	200A	350A	200A	350A
V_{DROM}	15								
$V_{RROM}(V)$	25								
	30								
	50								
	100		2N3668	S6200A	2N3870	S6210A	2N3896	S6220A	S6420A
	150								
	200	S5210B	2N3669	S6200B	2N3871	S6210B	2N3897	S6220B	S6420B
	250								
	300								
	400	S5210D	2N3670	S6200D	2N3872	S6210D	2N3898	S6220D	S6420D
	500								
	600	S5210M	2N4103	S6200M	2N3873	S6210M	2N3899	S6220M	S6420M
	700								
	750								
	800				S6400N		S6410N		S6420N
$I_{GT}(mA)$		40	40	15	40	15	40	15	40
$V_{GT}(V)$		3.5	2	2	2	2	2	2	2
	File No.	757	116	418	578	418	578	418	578

ITR Product Matrix

RCA SCR's		TO-48				
$I_{T(RMS)}$		16.0A	25.0A	Pul. Mod. 35.0A	FTO 35.0A	FTO 35A
I_{TSM}		125A	150A	150A	180A	250A
V_{DROM}	15					
$V_{RROM}(V)$	25	2N1842A	2N681			
	30					
	50	2N1843A	2N682			2N3654
	100	2N1844A	2N683		2N3650	2N3655
	150	2N1845A	2N684			
	200	2N1846A	2N685		2N3651	2N3656
	250	2N1847A	2N686			
	300	2N1848A	2N687		2N3652	2N3657
	400	2N1849A	2N688		2N3653	2N3658
	500	2N1850A	2N689			
	600		2N690	S6431M	S7430M	S7432M
	700					
	750					
	800					
$I_{GT}(mA)$		45	25	80	180	180
$V_{GT}(V)$		3.5	3	2	3	3
	File No.	28	96	247	408	724

FTO — Fast Turn-Off

For Horizontal-Deflection Circuits

RCA ITR's*		TO-66	
$I_{T(RMS)}$		TRACE 5A	RETRACE 5A
I_{TSM}		50A	50A
$V_{DROM}(V)$	400		S3800D
	500	S3800E	
	550		S3800EF
	600		S3800M
	650	S3800MF	
	700		S3800S
	750	S3800SF	
$I_{GT}(mA)$		40	45
$V_{GT}(V)$		4	4
File No.		639	639

*Integrated Thyristor/Rectifier

Rectifier Product Matrix

RCA Rectifiers		Mod. TO-1	DO-1				DO-26			
I_O		0.25A	0.75A	0.75A	1A	1A	0.75A	0.75A Insulated	1A	1A Insulated
I_{FSM}		30A	15A	15A	35A	35A	35A	35A	50A	50A
V_{RRM}(V)	50			1N536		1N2858A				
	100	D1300A	1N440B	1N537		1N2859A				
	200	D1300B	1N441B	1N538		1N2860A	1N3193	1N3253	1N5211	1N5215
	300		1N442B	1N539		1N2861A				
	400	D1300D	1N443B	1N540	1N1763A	1N2862A	1N3194	1N3254	1N5212	1N5216
	500		1N444B	1N1095	1N1764A	1N2863A				
	600		1N445B	1N547		1N2864A	1N3195	1N3255	1N5213	1N5217
	800						1N3196	1N3256	1N5214	1N5218
	1000							1N3563		
	File No.	784	5	3	89	91	41	41	245	245

RCA Rectifiers		DO-15		DO-4		DO-5	
I_O		1A	1.5A	6A	12A	20A	40A
I_{FSM}		30A	50A	160A	240A	350A	800A
V_{RRM}(V)	50	D1201F	1N5391	1N1341B	1N1199A	1N248C	1N1183A
	100	D1201A	1N5392	1N1342B	1N1200A	1N249C	1N1184A
	200	D1201B	1N5393	1N1344B	1N1202A	1N250C	1N1186A
	300		1N5394	1N1345B	1N1203A	1N1195A	1N1187A
	400	D1201D	1N5395	1N1346B	1N1204A	1N1196A	1N1188A
	500		1N5396	1N1347B	1N1205A	1N1197A	1N1189A
	600	D1201M	1N5397	1N1348B	1N1206A	1N1198A	1N1190A
	800	D1201N	1N5398				
	1000	D1201P	1N5399				
	File No.	495	478	58	20	6	38

Rectifier Product Matrix (cont'd)

Fast Recovery Types

RCA Rectifiers		DO-26	DO-15	DO-4				DO-5			
I_O		1A	1A	6A	6A	12A	12A	20A	20A	30A	40A
I_{FSM}		35A	50A	75A	125A	150A	250A	225A	300A	300A	700A
V_{RRM}(V)	50	D2601F	D2201F	1N3879	D2406F	1N3889	D2412F	1N3899	D2520F	1N3909	D2540F
	100	D2601A	D2201A	1N3880	D2406A	1N3890	D2412A	1N3900	D2520A	1N3910	D2540A
	200	D2601B	D2201B	1N3881	D2406B	1N3891	D2412B	1N3901	D2520B	1N3911	D2540B
	300			1N3882	D2406C	1N3892	D2412C	1N3902	D2520C	1N3912	
	400	D2601D	D2201D	1N3883	D2406D	1N3893	D2412D	1N3903	D2520D	1N3913	D2540D
	500										
	600	D2601M	D2201M		D2406M		D2412M		D2520M		D2540M
	800	D2601N	D2201N								
	1000										
Reverse Recovery Time trr											
	Typ.	200 ns.	200 ns.	–	200 ns.	–	200 ns.	–	200 ns.	–	200 ns.
	Max.	500 ns.	500 ns.	200 ns.	350 ns.	200 ns.	350 ns	200 ns.	350 ns.	200 ns.	350 ns.
	File No.	723	629	726	663	727	664	728	665	729	580

For Horizontal-Deflection Circuits

RCA Rectifiers	DO-26			DO-1		DO-15
I_o	0.5A*	1.6A*	1.9A*	–	–	1A
I_{FSM}	30A	70A	70A	70A	30A	50A
Trace			D2601M	D2103SF		D2201M
Commutating		D2601E		D2103S		D2201M
Linearity						D2201B
Regulator						D2201B
Clamp	D2600M				D2101S	
File No.	839	839	839	522	522	629

*$I_{F(RMS)}$ value.

Diac Product Matrix

For Triggering Triacs

RCA Diacs	DO-15	
	D3202Y	D3202U
I_{pk}	2A	2A
$V_{(BO)}$	29 min. 35 max. V	25 min. 40 max. V
$\lvert +V_{(BO)}\rvert - \lvert -V_{(BO)}\rvert$	+3 max. V	+3 max. V
$\lvert \Delta V\pm \rvert$	9 min. V	9 min. V
File No.	577	577

Application Information

TRIACS

LOW-CURRENT SENSITIVE-GATE

Current $I_{T(RMS)}$-A	Voltage Range - V	Package	Series	Typical Applications
1.6 - 2.5	100-400	TO-5 & TO-5 w Rad.	T2300 T2310 T2301 T2311 T2302 T2312	IC Control Circuit to Power Control

GENERAL PURPOSE

1.9	100-600	Mod. TO-5 w Rad.	T2312	General Purpose AC Power Switching ■ Light Control ■ Motor Control—Static & Speed ■ Heat/Comfort Control ■ Solid State Static Switching ■ Three Phase Power Control
2.5	600	Mod. TO-5	2N5757	
3.3	200-400	TO-66 w Rad.	T2710	
6	200-400	TO-220AB (VERSAWATT)	T2500	
6	200-400	TO-66	T2700	
6	200-500	TO-220AB (VERSAWATT)	T2801	
8	100-400	TO-220AB (VERSAWATT)	T2850	
8	200-600	TO-220AB (VERSAWATT)	T2800	
8	200-600	TO-220AB (VERSAWATT)	T2802	
10	200-600	Press-Fit	2N5568 T4101	
10	200-600	Stud	2N5570 T4111	
10	200-600	Isolated-Stud	T4121	
15	200-600	Press-Fit	2N5572 T4100	
15	200-600	Stud	2N5574 T4110	
15	200-600	Isolated-Stud	T4120	
15	200-400	TO-66	T4700	
30	200-600	Press-Fit	T6401	
30	200-600	Stud	T6411	
30	200-600	Isolated-Stud	T6421	
40	200-800	Press-Fit	2N5443 T6400	
40	200-800	Stud	2N5446 T6410	
40	200-800	Isolated-Stud	T6420	
60	200-600	Press-Fit, Flex. Id	T8401	
60	200-600	Stud Flex. Id	T8411	
60	200-600	Isolated-Stud Flex. Id	T8421	
80	200-600	Press-Fit, Flex. Id	T8430	
80	200-600	Stud, Flex. Id	T8440	
80	200-600	Isolated-Stud, Flex. Id	T8450	

400 Hz OPERATION

Current $I_{T(RMS)}$-A	Voltage Range - V	Package	Series	Typical Applications
0.5	200-400	TO-5	T2304 T2305	Airborne-Type Equipment and 60-Hz Applications Requiring High Commutating dv/dt ■ Motor Starters
6	200-400	Press-Fit	T4105	
6	200-400	Stud▲	T4115	
10	200-400	Press-Fit	T4104	
10	200-400	Stud▲	T4114	
15	200-400	Press-Fit	T4103	
15	200-400	Stud▲	T4113	
25	200-400	Press-Fit	T6405	
25	200-400	Stud▲	T6415	
40	200-400	Pres-Fit	T6404	
40	200-400	Stud▲	T6414	

▲On request, isolated-stud package types are available.

ZERO-VOLTAGE SWITCHING

Triacs in most series are characterized for applications utilizing zero-voltage switching with RCA-CA3058, CA3059, and CA3079 IC triggering circuits — see product matrix for types in each series

For types not listed, contact your RCA representative.

Application Information (continued)

SCR's

LOW-CURRENT SENSITIVE GATE

Current $I_{T(RMS)}$-A	Voltage Range - V	Package	Series	Typical Applications
4	15-600	TO-220AB (VERSAWATT)	S2060 S2061 S2062	Logic Interface to Power Control

GENERAL PURPOSE PHASE CONTROL

2	200-600	TO-8	2N4102	Fuel Igniters
3.3	200-600	TO-5 w Rad.	S2610	CD Ignition
4.5	100-600	TO-8	S2400	CD Ignition, "Crowbars"
7	200-600	Mod. TO-5	S2600	CD Ignition
7	200-600	TO-5 w Spdr.	S2620	CD Ignition
1.7	200-600	TO-66 w Rad.	S2710	CD Ignition,
5	200-600	TO-66	2N4101	Small Motor Control
8	100-400	TO-220AB (VERSAWATT)	S2800	CD Ignition, Regulators, Small Motor Control, and General Purpose
12.5	100-600	TO-3	2N4103	General Purpose
16	25-500	TO-48	2N1850A	
25	25-600	TO-48	2N690	
20	100-600	Press-Fit	S6200	
20	100-600	Stud	S6210	
20	100-600	Isolated-Stud	S6220	
35	100-800	Press-Fit	2N3873 S6400	
35	100-800	Stud	2N3899 S6410	
35	100-800	Isolated-Stud	S6420	

INVERTERS

5	200-600	TO-66	S3700	High-Frequency Power Supplies
5	600	TO-66	S3701	Laser Diode Driver
5	700-750	TO-66	S3702 S3703	110° TV Deflection
5	100-700	TO-66 & TO-66 w Rad.	S3704 S3714	Ultrasonics, Induction Heaters
5	500-600	TO-66	S3705 S3706	TV Deflection
10	200-600	Stud	S5210	High-Frequency Power Supplies
35	600	TO-48	S6431	Pulse Modulators
35	50-600	TO-48	2N3653 2N3658	Inverters, Choppers

TR's

TV HORIZONTAL DEFLECTION

5	400-750	TO-66	S3800	Commutating and Trace Switches

IACS

LEAD-TYPE PLASTIC PACKAGE

Peak Current $I_{T(RMS)-pk}$	Voltage Range - V	Package	Series	Typical Applications
190 mA	25-40 (V_{BO})	DO-15	D3202	For Triggering Triacs

Application Information (continued)

RECTIFIERS

STANDARD—Lead-Type Hermetic and Plastic Packages

Current I_o-A	Voltage Range - V	Package	Series	Typical Applications
0.5	100-400	"Mod. TO-1" (21d)	D1300	General Purpose
0.65-0.75	50-600	DO-1	1N445B 1N547	
1	50-600	DO-1	1N1764A 1N2864A	
1-1.5	50-1000	DO-15	1N5399 D1201	
0.4-0.75	200-800	DO-26	1N3196	
0.75-1	200-800	DO-26	1N5214	
0.4-0.75	200-1000	DO-26 (Insul. Case)	1N3563	
0.75-1	200-800	DO-26 (Insul. Case)	1N5218	

STANDARD—Stud Package

6	50-600	DO-4	1N1348B	General Purpose
12	50-600	DO-4	1N1206A	
20	50-600	DO-5	1N1198A	
40	50-600	DO-5	1N1190A	

FAST-RECOVERY TYPE—Lead-Type Hermetic and Plastic Packages

Current $I_{F(RMS)}$-A	Voltage Range - V	Package	Series	Typical Applications
0.5	600	DO-26	D2600	TV Deflection, Inverters, and High-Frequency Power Supplies
1	700	DO-1	D2101	
1.5	50-800	DO-15	D2201	
1.9	50-800	DO-26	D2601	
3	700-750	DO-1	D2103	

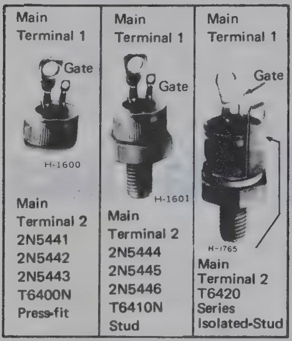
FAST-RECOVERY TYPE—Stud Package

9	50-600	DO-4	1N3883 D2406	Inverters and High-Frequency Power Supplies
18	50-600	DO-4	1N3893 D2412	
30	50-600	DO-5	1N3903 D2520	
45	50-400	DO-5	1N3913	
60	50-600	DO-5	D2540	

Technical Data-Triacs

RCA
Solid State
Division

Thyristors
2N5441 – 2N5446
T6400 T6410 T6420 Series



40-A Silicon Triacs

Features:

- di/dt Capability = 100 A/μs
- Shorted-Emitter, Center-Gate Design
- Low Switching Losses
- Low On-State Voltage at High Current Levels
- Low Thermal Resistance

Package \ Voltage	200 V Types	400 V Types	600 V Types	800 V Types
Press-Fit (T6400-Series)	2N5441	2N5442	2N5443	T6400N (40925)
Stud (T6410 Series)	2N5444	2N5445	2N5446	T6410N (40926)
Isolated-Stud (T6420 Series)	T6420B (40688)	T6420D (40689)	T6420M (40690)	T6420N (40927)

Numbers in parentheses (e.g. 40925) are former RCA type numbers.

RCA triacs are gate-controlled, full-wave silicon ac switches. They are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate-triggering voltages.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		2N5441 2N5444 T6420B	2N5442 2N5445 T6420D	2N5443 2N5446 T6420M	T6400N T6410N T6420N	
***REPETITIVE PEAK OFF-STATE VOLTAGE:●**	V_{DROM}					
Gate open, T_J = −65 to 110°C		200	400	600	800	V
RMS ON-STATE CURRENT (Conduction angle = 360°):	$I_{T(RMS)}$					
Case temperature						
* T_C = 70°C (Press-fit types)		40				A
* = 65°C (Stud types)		40				A
= 60°C (Isolated-stud types)		40				A
For other conditions		See *Fig. 3*				
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}					
For one cycle of applied principal voltage, T_C as above						
* 60 Hz (sinusoidal)		300				A
50 Hz (sinusoidal)		265				A
For more than one cycle of applied principal voltage		See *Fig. 4*				
RATE OF CHANGE OF ON-STATE CURRENT:	di/dt					
$V_{DM} = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.1 μs (See *Fig. 13*)		100				A/μs
FUSING CURRENT (for Triac Protection):	I^2t					
T_J = −65 to 110°C, t = 1.25 to 10 ms		450				A^2s
***PEAK GATE-TRIGGER CURRENT:■**	I_{GTM}					
For 1 μs max., See *Fig. 7*		12				A
***GATE POWER DISSIPATION:**						
PEAK (For 10 μs max., $I_{GTM} \leq$ 4 A, See *Fig. 7*)	P_{GM}	40				W
AVERAGE	$P_{G(AV)}$	0.75				W
***TEMPERATURE RANGE:▲**						
Storage	T_{stg}	−65 to 150				°C
Operating (Case)	T_C	−65 to 110				°C
***TERMINAL TEMPERATURE** (During soldering):	T_T					
For 10 s max. (terminals and case)		225				°C
STUD TORQUE:	τ_s					
Recommended		35				in-lb
Maximum (DO NOT EXCEED)		50				in-lb

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* In accordance with JEDEC registration data format (JS-14, RDF2) filed for the JEDEC (2N-Series) types.

● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

■ For either polarity of gate voltage (V_G) with reference to main terminal 1.

▲ For temperature measurement reference point, see Dimensional Outline.

ELECTRICAL CHARACTERISTICS

At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS			UNITS
		MIN.	TYP.	MAX.	
Peak Off-State Current:♠ Gate open, T_J = 110°C, V_{DROM} = Max. rated value	I_{DROM}	–	0.2	4*	mA
Maximum On-State Voltage:♠	V_{TM}				V
For i_T = 100 A (peak), T_C = 25°C		–	1.7	2	
For i_T = 56 A (peak), T_C = 25°C		–	1.5	1.85*	
DC Holding Current:♠ Gate open, Initial principal current = 500 mA (dc), v_D = 12V:	I_{HO}				mA
T_C = 25°C		–	25	60	
T_C = -65°C		–	–	100*	
For other case temperatures		See *Fig. 6*			
Critical Rate of Rise of Commutation Voltage:♠ For v_D = V_{DROM}, $I_{T(RMS)}$ = 40 A, commutating di/dt = 22 A/ms, gate unenergized, (See *Fig. 14*):	dv/dt				v/μs
T_C = 70°C (Press-fit types)		5*	30	–	
= 65°C (Stud types)		5*	30	–	
= 60°C (Isolated-stud types)		5	30	–	
Critical Rate of Rise of Off-State Voltage:♠ For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 110°C:	dv/dt				V/μs
2N5441, 2N5444, T6420B.		50*	200	–	
2N5442, 2N5445, T6420D.		30*	150	–	
2N5443, 2N5446, T6420M		20*	100	–	
T6400N, T6410N, T6420N.		10	75	–	
DC Gate-Trigger Current:♠♦ Mode V_{MT2} V_G	I_{GT}				mA
For v_D = 12 V (dc) I^+ positive positive		–	15	50	
R_L = 30 Ω III^- negative negative		–	20	50	
T_C = 25°C I^- positive negative		–	30	80	
III^+ negative positive		–	40	80	
Mode V_{MT2} V_G					
For v_D = 12 V (dc) I^+ positive positive		–	–	125*	
R_L = 30 Ω III^- negative negative		–	–	125*	
T_C = -65°C I^- positive negative		–	–	240*	
III^+ negative positive		–	–	240*	
For other case temperatures		See *Figs. 8 & 9*			
DC Gate-Trigger Voltage:♠♦ For v_D = 12 V (dc), R_L = 30 Ω,	V_{GT}				V
T_C = 25°C		–	1.35	2.5	
= -65°C		–	1.8	3.4*	
For other case temperatures		See *Fig. 10*			
For v_D = V_{DROM}, R_L = 125 Ω, T_C = 110°C		0.2	–	–	
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For v_D = V_{DROM}, I_{GT} = 200 mA, t_r = 0.1 μs, i_T = 60 A (peak), T_C = 25°C (See *Figs. 11 & 15*)	t_{gt}	–	1.7	3	μs
Thermal Resistance, Junction-to-Case: Steady-State	$R_{\theta JC}$				°C/W
Press-fit types		–	–	0.8*	
Stud types		–	–	0.9*	
Isolated-stud types		–	–	1	
Transient (Press-fit & stud types)		See *Fig. 12*			

* In accordance with JEDEC registration data format (JS-14, RDF 2) filed for the JEDEC (2N-Series) types.

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

♦ For either polarity of gate voltage (V_G) with reference to main terminal 1.

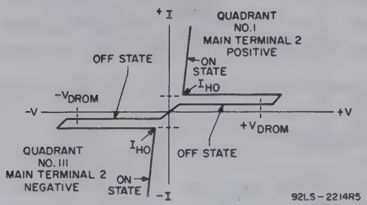

+I
QUADRANT
NO.I
MAIN TERMINAL 2
POSITIVE
OFF STATE
ON
STATE
I_{HO}
$-V_{DROM}$
-V
+V
$+V_{DROM}$
QUADRANT
NO. III
MAIN TERMINAL 2
NEGATIVE
I_{HO}
OFF STATE
ON
STATE
-I
92LS-2214R5

Fig.1—Principal voltage-current characteristic.

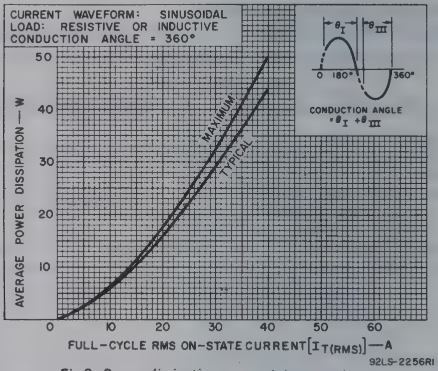


Fig.2—Power dissipation vs. on-state current.

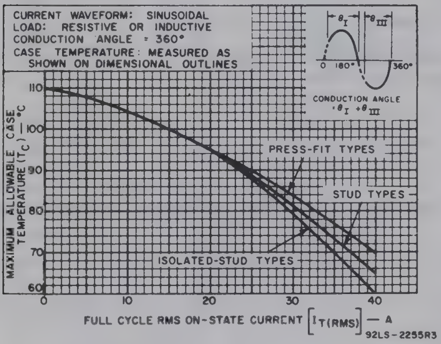


Fig.3—Maximum allowable case temperature vs. on-state current.

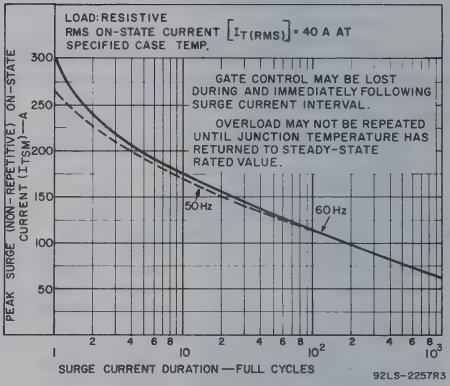


Fig.4—Peak surge on-state current vs. surge current duration.

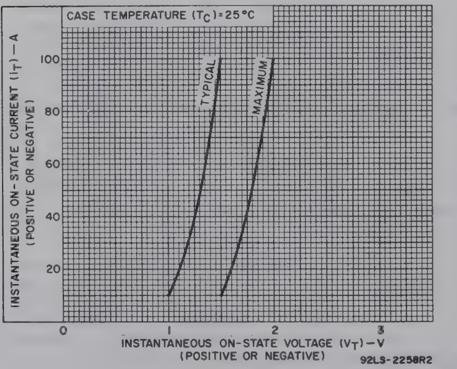


Fig.5—On-state current vs. on-state voltage.

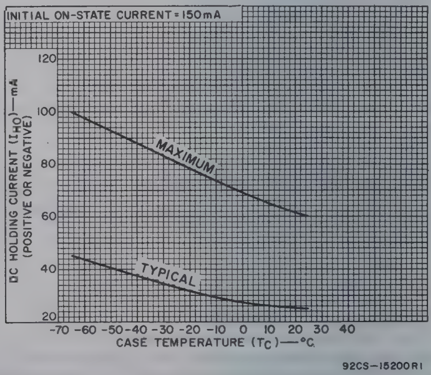


Fig.6—DC holding current vs. case temperature.

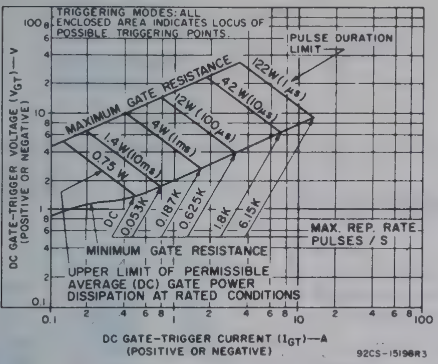


Fig.7—Gate-trigger characteristics and limiting conditions for determination of permissable gate-trigger pulses.

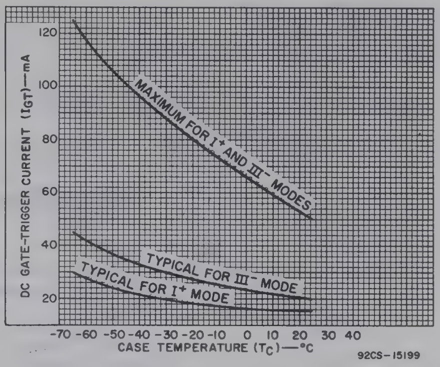


Fig.8—DC gate-trigger current vs. case temperature (I⁺ & III⁻ modes).

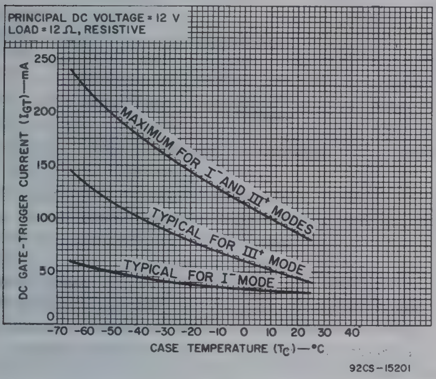


Fig.9—DC gate-trigger current vs. case temperature (I⁻ & III⁺ modes).

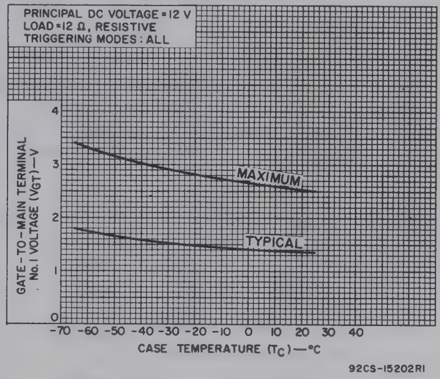


Fig.10—DC gate-trigger voltage vs. case temperature.

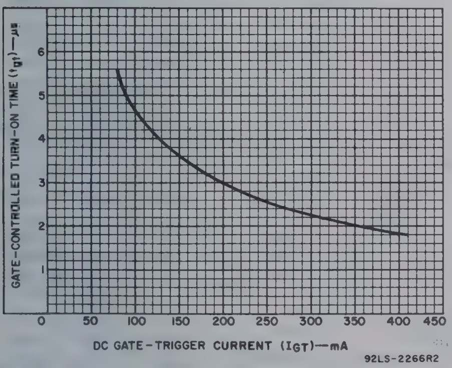


Fig.11—Turn-on time vs. gate-trigger current.

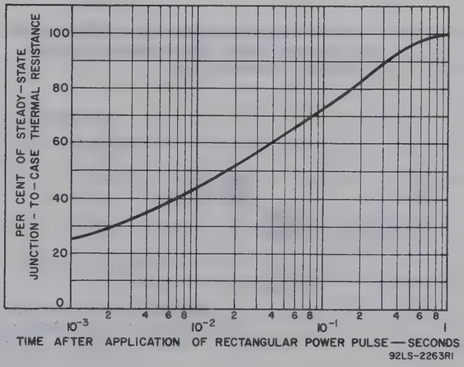
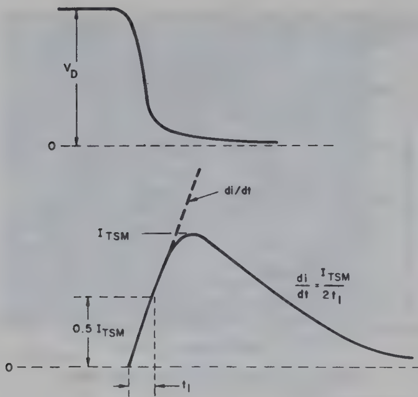
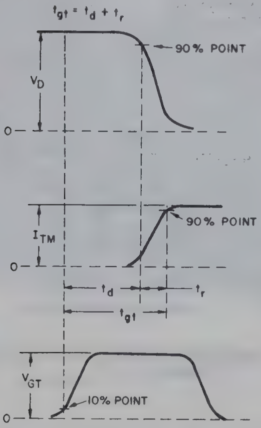


Fig.12—Transient junction-to-case thermal resistance vs. time for press-fit and stud types.



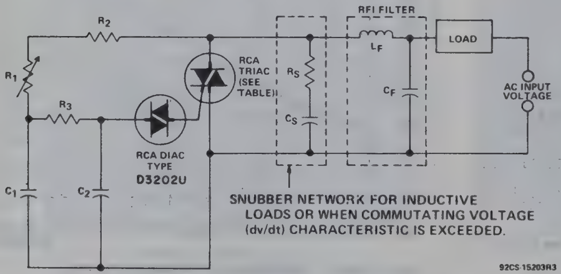
92CS-17063

Fig.13—Rate of change of on-state current with time (defining di/dt).



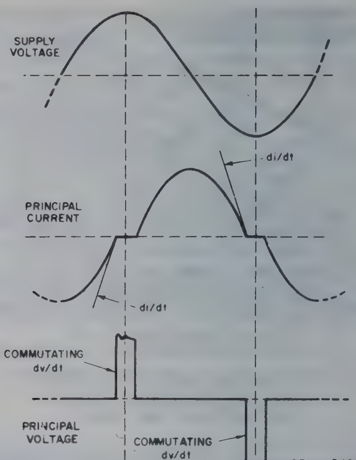
92LS-2410R2

Fig. 15— Relationship between off-state voltage, on-stage current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).


RFI FILTER
R$_2$
R$_1$
R$_3$
C$_1$
C$_2$
RCA TRIAC (SEE TABLE)
RCA DIAC TYPE D3202U
R$_S$
C$_S$
L$_F$
C$_F$
LOAD
AC INPUT VOLTAGE
SNUBBER NETWORK FOR INDUCTIVE LOADS OR WHEN COMMUTATING VOLTAGE (dv/dt) CHARACTERISTIC IS EXCEEDED.

92CS-15203R3

Fig.16—Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.



92LS-2409R4

Fig.14—Relationship between supply voltage and principal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

TERMINAL CONNECTIONS

No. 1—Gate
No. 2—Main Terminal 1
Case, No. 3—Main Terminal 2

WARNING: The ceramic body of this device contains beryllium oxide. Do not crush, grind, or abrade these portions because the dust resulting from such action may be hazardous if inhaled. Disposal should be by burial.

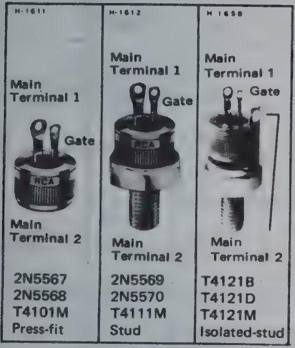
AC INPUT VOLTAGE		120V 60Hz	240V 60Hz	240V 50Hz
C_1		0.1μF 200V	0.1μF 400V	0.1μF 400V
C_2		0.1μF 100V	0.1μF 100V	0.1μF 100V
R_1		100KΩ 1/2W	200KΩ 1W	250KΩ 1W
R_2		2.2KΩ 1/2W	3.3KΩ 1/2W	3.3KΩ 1/2W
R_3		15KΩ 1/2W	15KΩ 1/2W	15KΩ 1/2W
SNUBBER NETWORK FOR 40-A (RMS)● INDUCTIVE LOAD	C_S	0.18-0.22μF 200V	0.18-0.22μF 400V	0.18-0.22μF 400V
	R_S	330-390Ω 1/2W	330-390Ω 1/2W	330-390Ω 1/2W
RFI FILTER	C_F*	0.1μF 200V	0.1μF 400V	0.1μF 400V
	L_F*	100μH	200μH	200μH
RCA TRIACS		2N5441 2N5444 T6420B	2N5442 2N5445 T6420D	2N5442 2N5445 T6420D

● For other RMS-current values refer to RCA Application Note AN-4745.

* Typical values for lamp dimming circuits.

RCA
Solid State
Division

Thyristors
2N5567 – 2N5570
T4101 T4111 T4121 Series



10-A Silicon Triacs

Features:

- di/dt Capability = 150 A/μs
- Shorted-Emitter, Center-Gate Design
- Low Switching Losses
- Low On-State Voltage at High Current Levels
- Low Thermal Resistance

Package \ Voltage	200 V Types	400 V Types	600 V Types
Press-Fit (T4101 Series)	2N5567	2N5568	T4101M (40795)
Stud (T4111 Series)	2N5569	2N5570	T4111M (40796)
Isolated-Stud (T4121 Series)	T4121B (40799)	T4121D (40800)	T4121M (40801)

Numbers in parentheses (e.g. 40799) are former RCA type numbers.

These RCA triacs are gate-controlled, full-wave silicon ac switches. They are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

These triacs are intended for control of ac loads in applications such as heating controls, motor controls, arc-welding equipment, light dimmers, and power switching systems.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		2N5567 2N5569 T4121B	2N5568 2N5570 T4121D	T4101M T4111M T4121M	
***REPETITIVE PEAK OFF-STATE VOLTAGE:●**					
Gate open, T_J = –65 to 100° C	V_{DROM}	200	400	600	V
***RMS ON-STATE CURRENT (Conduction angle = 360°):**					
Case temperature (T_C) = 85° C	$I_{T(RMS)}$		10		A
For other conditions			See *Fig. 3*		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}				
For one cycle of applied principal voltage, T_C = 85° C					
* 60 Hz (sinusoidal)			100		A
50 Hz (sinusoidal)			85		A
For more than one cycle of applied principal voltage			See *Fig. 4*		
RATE-OF-CHANGE OF ON-STATE CURRENT:					
V_{DM} = V_{DROM}, I_{GT} = 160 mA, t_r = 0.1 μs (See *Fig. 13)*	di/dt		150		A/μs
FUSING CURRENT (for Triac Protection):					
T_J = –65 to 100°C, t = 1.25 to 10 ms	I^2t		50		A^2s
PEAK GATE-TRIGGER CURRENT:■					
For 1 μs max., See *Fig. 7*	I_{GTM}		4		A
***GATE POWER DISSIPATION:**					
PEAK (For 1 μs max., $I_{GTM} \leq 4$ A, See *Fig. 7)*	P_{GM}		16		W
AVERAGE	$P_{G(AV)}$		0.5		W
***TEMPERATURE RANGE:▲**					
Storage	T_{stg}		–65 to 150		°C
Operating (Case)	T_C		–65 to 100		°C
***TERMINAL TEMPERATURE (During soldering):**					
For 10 s max. (terminals and case)	T_T		225		°C
STUD TORQUE:	τ_s				
Recommended			35		in-lb
Maximum (DO NOT EXCEED)			50		in-lb

* In accordance with JEDEC registration data format (JS-14, RDF 2) filed for the JEDEC (2N-Series) types.
● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.
▲ For temperature measurement reference point, see Dimensional Outline.

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	Mode	V_{MT2}	V_G	SYMBOL	LIMITS Min.	LIMITS Typ.	LIMITS Max.	UNITS
Peak Off-State Current:♠ Gate open, T_J = 100° C, V_{DROM} = Max. rated value				I_{DROM}	–	0.1	2*	mA
Maximum On-State Voltage:♠ For i_T = 14 A (peak), T_C = 25° C				V_{TM}	–	1.35	1.65*	V
DC Holding Current:♠ Gate open, Initial principal current = 500 mA (DC), v_D = 12V:								
T_C = 25° C				I_{HO}	–	15	30	mA
T_C = –65° C					–	75	200*	
For other case temperatures						See *Fig. 6*		
Critical Rate-of-Rise of Commutation Voltage:♠ For v_D = V_{DROM}, $I_{T(RMS)}$ = 10 A, commutating di/dt = 5.4 A/ms, gate unenergized, T_C = 85° C (See *Fig. 14*)				dv/dt	2*	5	–	V/µs
Critical Rate-of-Rise of Off-State Voltage:♠ For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 100° C:								
2N5567, 2N5569, T4121B				dv/dt	30*	150	–	V/µs
2N5568, 2N5570, T4121D					20*	100	–	
T4101M, T4111M, T4121M					10	75	–	
DC Gate-Trigger Current:♠♦ For v_D = 12 V (DC), R_L = 30 Ω, T_C = 25° C	I+	positive	positive	I_{GT}	–	10	25	mA
	III-	negative	negative		–	10	25	
	I-	positive	negative		–	20	40	
	III+	negative	positive		–	20	40	
For v_D = 12 V (DC), R_L = 30 Ω, T_C = –65° C	I+	positive	positive		–	45	100*	
	III-	negative	negative		–	45	100*	
	I-	positive	negative		–	80	150*	
	III+	negative	positive		–	80	150*	
For other case temperatures						See *Figs. 8 & 9*		
DC Gate-Trigger Voltage:♠♦ For v_D = 12 V(DC), R_L = 30 Ω T_C = 25° C				V_{GT}		1	2.5	V
T_C = –65° C						2	4*	
For other case temperatures						See *Fig. 10*		
For v_D = V_{DROM}, R_L = 125 Ω, T_C = 100° C					0.2	–	–	
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For v_D = V_{DROM}, I_{GT} = 160 mA, t_r = 0.1 µs, i_T = 15 A (peak), T_C = 25° C (See *Figs. 11 & 15*)				t_{gt}	–	1.6	2.5	µs
Thermal Resistance: **Junction-to-Case:** Steady-State				$\theta_{J\text{-}C}$	–	–	1*	°C/W
Transient						See *Fig. 12*		
Junction-to-Isolated Hex (Stud, see Dim. Outline): Steady-State				$\theta_{J\text{-}IH}$	–	–	1.1	

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* In accordance with JEDEC registration data format (JS-14, RDF 2) filed for the JEDEC (2N-Series) types.

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

♦ For either polarity of gate voltage (V_G) with reference to main terminal 1.

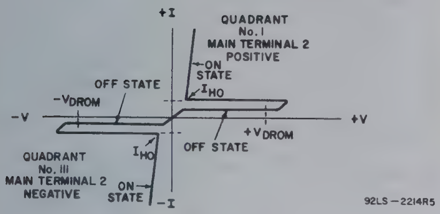

+I
QUADRANT
No. I
MAIN TERMINAL 2
POSITIVE
ON
STATE
OFF STATE
I_{HO}
$-V_{DROM}$
−V
+V
$+V_{DROM}$
OFF STATE
QUADRANT
No. III
MAIN TERMINAL 2
NEGATIVE
I_{HO}
ON
STATE
−I
92LS—2214R5

Fig. 1 – Principal voltage-current characteristic.

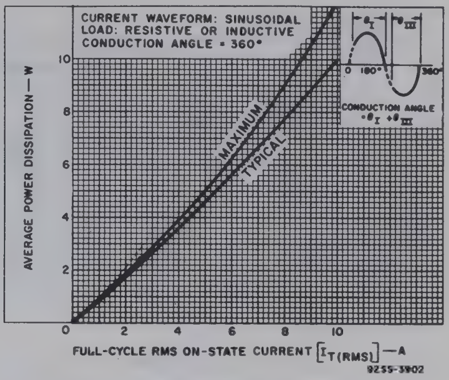


Fig. 2 – Power dissipation vs. on-state current.

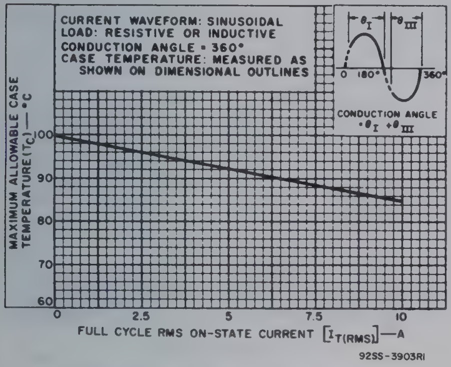


Fig. 3 – Maximum allowable case temperature vs. on-state current.

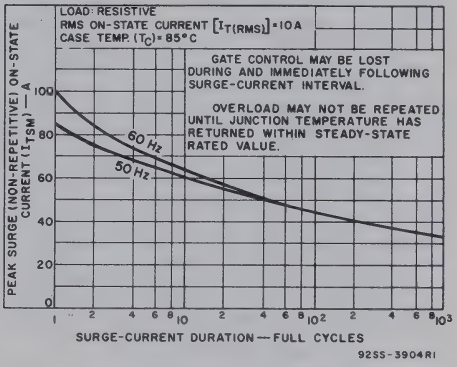


Fig. 4 – Peak surge on-state current vs. surge current duration.

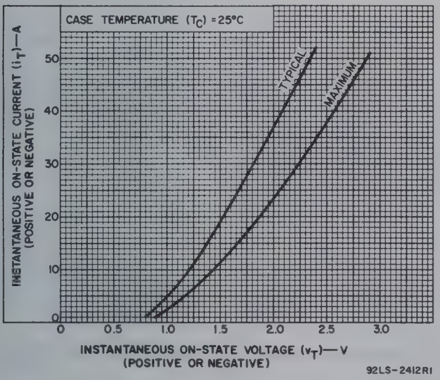


Fig. 5 – On-state current vs. on-state voltage.

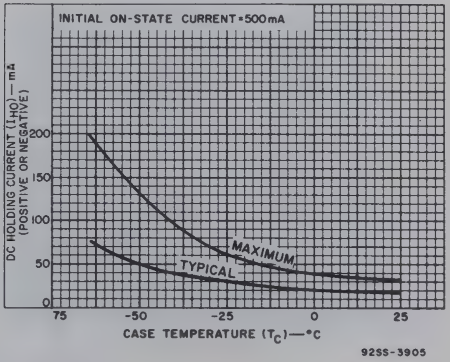
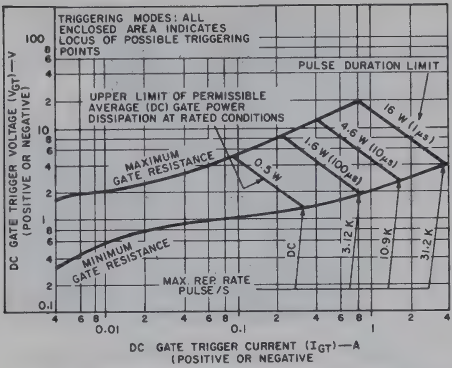
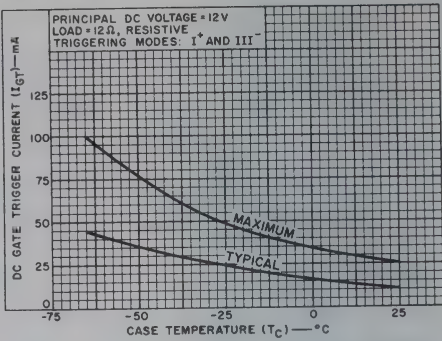


Fig. 6 – DC holding current vs. case temperature.



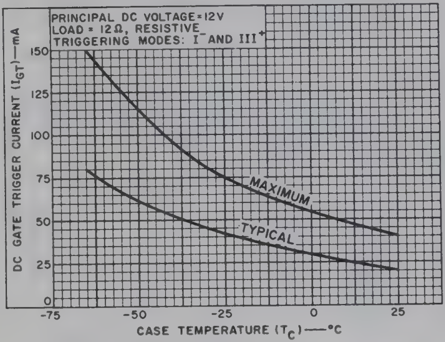
92CS-17058

Fig. 7 – Gate trigger characteristics and limiting conditions for determination of permissible gate trigger pulses.



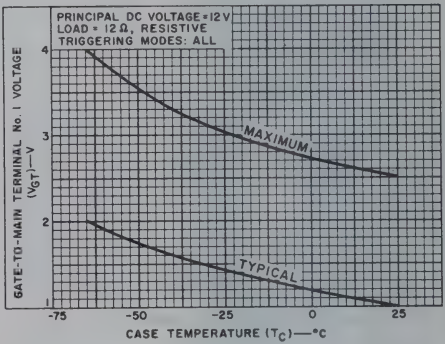
92SS-3914

Fig. 8 – DC gate-trigger current vs. case temperature (1$^+$ & III$^-$ modes).



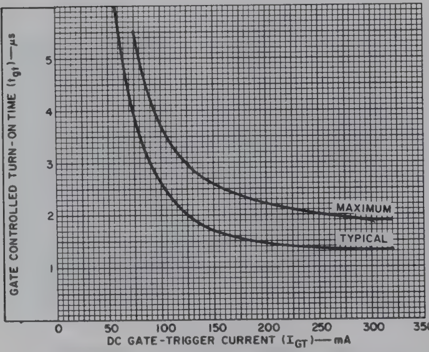
92SS-3915

Fig. 9 – DC gate-trigger current vs. case temperature (1$^-$ & III$^+$ modes).



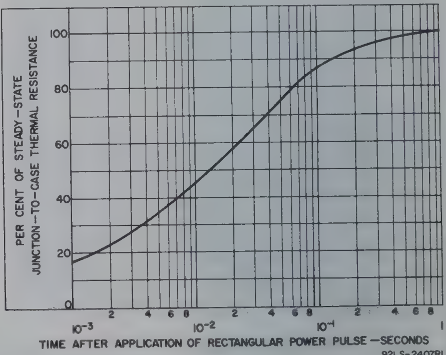
92SS-3911

Fig. 10 – DC gate-trigger voltage vs. case temperature.



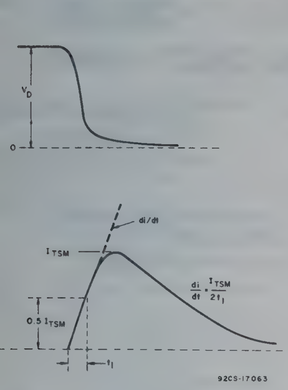
92CS-17062

Fig. 11 – Turn-on time vs. gate trigger current.



92LS-2407R1

Fig. 12 – Transient junction-to-case thermal resistance vs. time.



. 13 — *Rate-of-change of on-state current with time (defining di/dt).*

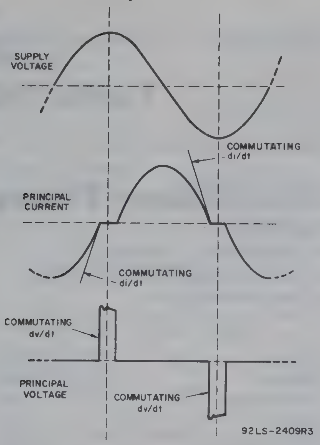


Fig. 14—Relationship between supply voltage and prinicpal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

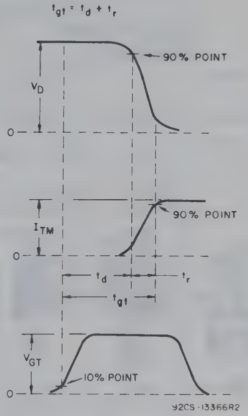
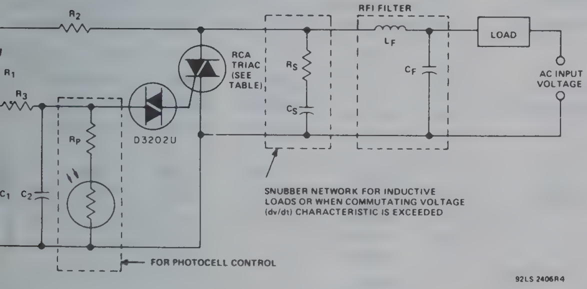


Fig. 15—Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).


R_2
R_1
R_3
C_1
C_2
R_P
D3202U
RCA TRIAC (SEE TABLE)
R_S
C_S
RFI FILTER
L_F
C_F
LOAD
AC INPUT VOLTAGE
SNUBBER NETWORK FOR INDUCTIVE LOADS OR WHEN COMMUTATING VOLTAGE (dv/dt) CHARACTERISTIC IS EXCEEDED
FOR PHOTOCELL CONTROL
92LS 2406R4

. 16 — *Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.*

AC INPUT VOLTAGE		120V 60Hz	240V 60Hz	240V 50Hz
C_1		0.1μF 200V	0.1μF 400V	0.1μF 400V
C_2		0.1μF 100V	0.1μF 100V	0.1μF 100V
R_1		100KΩ 1/2W	200KΩ 1W	250KΩ 1W
R_2		2.2KΩ 1/2W	3.3KΩ 1/2W	3.3KΩ 1/2W
R_3		15KΩ 1/2W	15KΩ 1/2W	15KΩ 1/2W
PHOTOCELL CONTROL	R_P	1.2KΩ 2W	1.2KΩ 2W	1.2KΩ 2W
SNUBBER NETWORK	C_S	0.1μF 200V	0.1μF 400V	0.1μF 400V
	R_S	100Ω 1/2W	100Ω 1/2W	100Ω 1/2W
RFI FILTER	C_F*	0.1μF 200V	0.1μF 400V	0.1μF 400V
	L_F*	100μH	200μH	200μH
RCA TRIACS		2N5567 2N5569 T4121B	2N5568 2N5570 T4121D	2N5568 2N5570 T4121D

*Typical values for lamp dimming circuits

WARNING:
The RCA isolated-stud package thyristors should be handled with care. The ceramic portion of these thyristors contains BERYLLIUM OXIDE as a major ingredient. Do not crush, grind, or abrade these portions of the thyristors because the dust resulting from such action may be hazardous if inhaled.

TERMINAL CONNECTIONS

No.1—Gate
No.2—Main Terminal 1
No.3—Main Terminal 2

RCA
Solid State
Division

Thyristors
2N5571 – 2N5574
T4100 T4110 T4120 Series

H-1611
Main Terminal 1
Gate
Main Terminal 2

2N5571
2N5572
T4100M
Press-fit

H-1612
Main Terminal 1
Gate
Main Terminal 2

2N5573
2N5574
T4110M
Stud

H-1658
Main Terminal 1
Gate
Main Terminal 2

T4120B
T4120D
T4120M
Isolated-stud

15-A Silicon Triacs

Features:

- di/dt Capability = 150 A/μs
- Shorted-Emitter Center-Gate Design
- Low Switching Losses
- Low On-State Voltage at High Current Levels
- Low Thermal Resistance

Package \ Voltage	200 V Types	400 V Types	600 V Types
Press-Fit (T4100 Series)	2N5571	2N5572	T4100M (40797)
Stud (T4110 Series)	2N5573	2N5574	T4110M (40798)
Isolated-Stud (T4120 Series)	T4120B (40802)	T4120D (40803)	T4120M (40804)

Numbers in parentheses (e.g. 40802) are former RCA type numbers.

These RCA triacs are gate-controlled, full-wave silicon ac switches. They are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

These triacs are intended for control of ac loads in applications such as heating controls, motor controls, arc-welding equipment, light dimmers, and power switching systems.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		2N5571 2N5573 T4120B	2N5572 2N5574 T4120D	T4100M T4110M T4120M	
***REPETITIVE PEAK OFF-STATE VOLTAGE:**●					
Gate open, T_J = −65 to 100° C	V_{DROM}	200	400	600	V
***RMS ON-STATE CURRENT (Conduction angle = 360°):**					
Case temperature	$I_{T(RMS)}$				
T_C = 80° C (Press-fit & stud types)		15			A
= 75° C (Isolated-stud types)		15			A
For other conditions		See *Fig. 3*			
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}				
For one cycle of applied principal voltage, T_C as above					
* 60 Hz (sinusoidal)		100			A
50 Hz (sinusoidal)		85			A
For more than one cycle of applied principal voltage		See *Fig. 4*			
RATE-OF-CHANGE OF ON-STATE CURRENT:					
V_{DM} = V_{DROM}, I_{GT} = 160 mA, t_r = 0.1 μs (See *Fig. 13)*	di/dt	150			A/μs
FUSING CURRENT (for Triac Protection):					
T_J = −65 to 100°C, t = 1.25 to 10 ms	I^2t	50			A^2s
PEAK GATE-TRIGGER CURRENT:■					
For 1 μs max., See *Fig. 7*	I_{GTM}	4			A
***GATE POWER DISSIPATION:**					
PEAK (For 1 μs max., $I_{GTM} \leq$ 4 A, See *Fig. 7)*	P_{GM}	16			W
AVERAGE	$P_{G(AV)}$	0.5			W
***TEMPERATURE RANGE:**▲					
Storage	T_{stg}	−65 to 150			°C
Operating (Case)	T_C	−65 to 100			°C
***TERMINAL TEMPERATURE (During soldering):**					
For 10 s max. (terminals and case)	T_T	225			°C
STUD TORQUE:	τ_s				
Recommended		35			in-lb
Maximum (DO NOT EXCEED)		50			in-lb

* In accordance with JEDEC registration data format (JS-14, RDF 2) filed for the JEDEC (2N-Series) types.
● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.
▲ For temperature measurement reference point, see Dimensional Outline.

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	SYMBOL	LIMITS			UNITS
		Min.	Typ.	Max.	
Peak Off-State Current:♠ Gate open, T_J = 100° C, V_{DROM} = Max. rated value	I_{DROM}	–	0.2	2*	mA
Maximum On-State Voltage:♠ For i_T = 21 A (peak), T_C = 25° C	V_{TM}	–	1.4	1.8*	V
DC Holding Current:♠ Gate open, Initial principal current = 500 mA (DC), v_D = 12V:	I_{HO}				mA
T_C = 25° C		–	20	75	
T_C = −65° C		–	75	300*	
For other case temperatures			See *Fig. 6*		
Critical Rate-of-Rise of Commutation Voltage:♠ For v_D = V_{DROM}, $I_{T(RMS)}$ = 15 A, commutating di/dt = 8 A/ms, gate unenergized, (See *Fig. 14*):	dv/dt				V/μs
T_C = 80° C (Press-fit & stud types)		2*	10	–	
= 75° C (Isolated-stud)		2	10	–	
Critical Rate-of-Rise of Off-State Voltage:♠ For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 100° C:	dv/dt				V/μs
2N5571, 2N5573, T4120B		30*	150	–	
2N5572, 2N5574, T4120D		20*	100	–	
T4100M, T4110M, T4120M		10	75	–	
DC Gate-Trigger Current:♠♦ For v_D = 12 V (DC), R_L = 30 Ω, T_C = 25° C Mode V_{MT2} V_G	I_{GT}				mA
I^+ positive positive		–	20	50	
III^- negative negative		–	20	50	
I^- positive negative		–	35	80	
III^+ negative positive		–	35	80	
For v_D = 12 V (DC), R_L = 30 Ω, T_C = −65° C Mode V_{MT2} V_G					
I^+ positive positive		–	75	150*	
III^- negative negative		–	75	150*	
I^- positive negative		–	100	200*	
III^+ negative positive		–	100	200*	
For other case temperatures			See *Figs. 8 & 9*		
DC Gate-Trigger Voltage:♠♦ For v_D = 12 V(DC), R_L = 30 Ω,	V_{GT}				V
T_C = 25° C		–	1	2.5	
T_C = -65° C		–	2	4*	
For other case temperatures			See *Fig. 10*		
For v_D = V_{DROM}, R_L = 125 Ω, T_C = 100° C		0.2	–	–	
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For v_D = V_{DROM}, I_{GT} = 160 mA, t_r = 0.1 μs, i_T = 25 A (peak), T_C = 25° C (See *Figs. 11 & 15*)	t_{gt}	–	1.6	2.5	μs
Thermal Resistance: **Junction-to-Case:**					°C/W
Steady-State	$R_{\theta JC}$	–	–	1*	
Transient			See *Fig. 12*		
Junction-to-Isolated Hex (Stud, see Dim. Outline): Steady-State	$R_{\theta JIH}$	–	–	1.1	

In accordance with JEDEC registration data format (JS-14, RDF 2) filed for the JEDEC (2N-Series) types.

For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

For either polarity of gate voltage (V_G) with reference to main terminal 1.

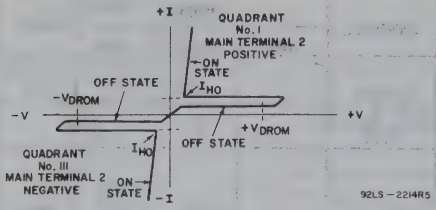


Fig. 1 — Principal voltage-current characteristic.

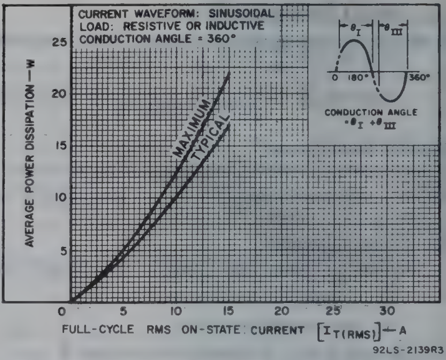


Fig. 2 — Power dissipation vs. on-state current.

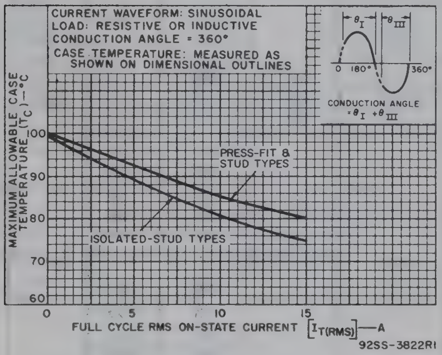


Fig. 3 — Maximum allowable case temperature vs. on-state current.

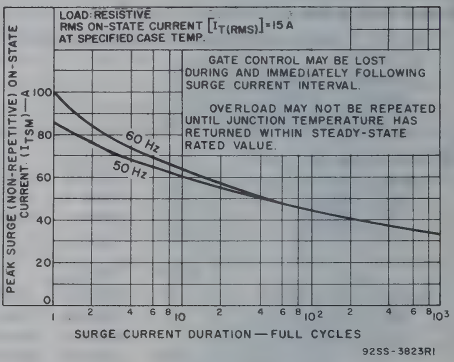


Fig. 4 — Peak surge on-state current vs. surge current duration.

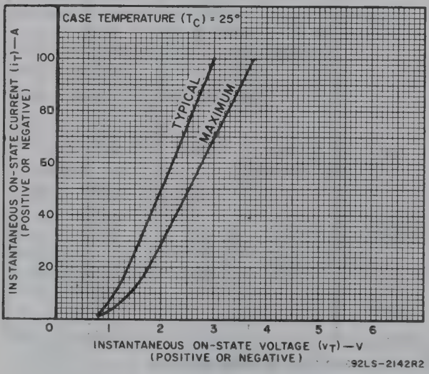


Fig. 5 — On-state current vs. on-state voltage.

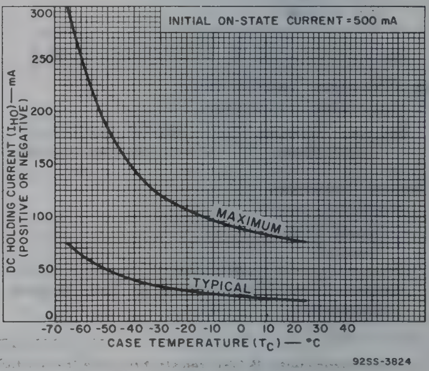
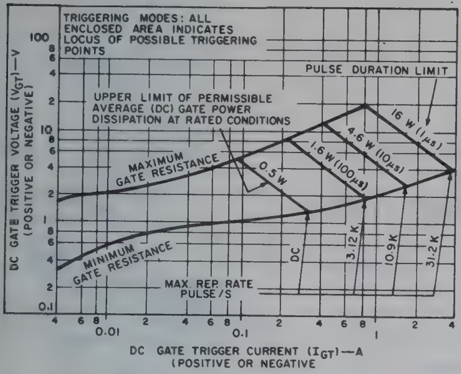
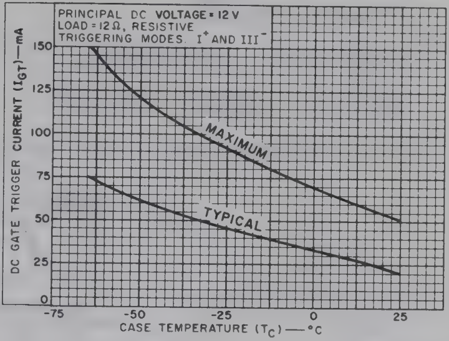


Fig. 6 — DC holding current vs. case temperature.



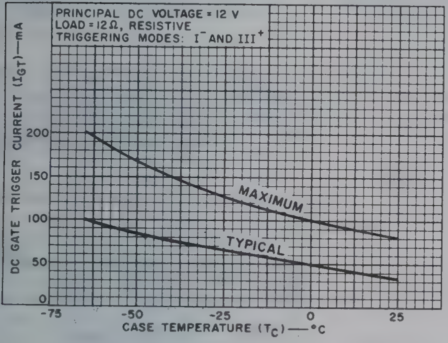
92CS-17058

Fig. 7 – Gate trigger characteristics and limiting conditions for determination of permissible gate trigger pulses.



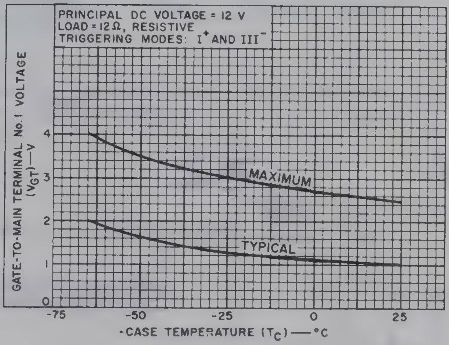
92SS-3825

Fig. 8 – DC gate-trigger current vs. case temperature (1^+ & III^- modes).



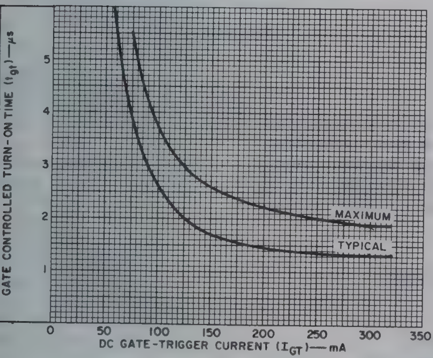
92SS-3826

Fig. 9 – DC gate-trigger current vs. case temperature (1^- & III^+ modes).



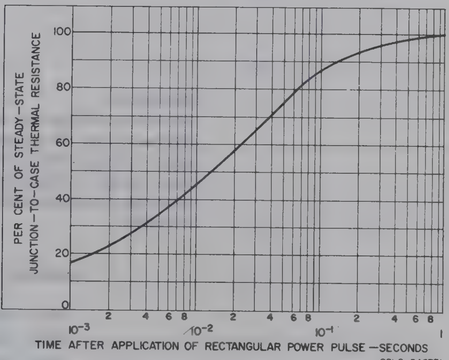
92SS-3918

Fig. 10 – DC gate-trigger voltage vs. case temperature.



92CS-17062

Fig. 11 – Turn-on time vs. gate trigger current.



92LS-2407R1

Fig. 12 – Transient junction-to-case thermal resistance vs. time.

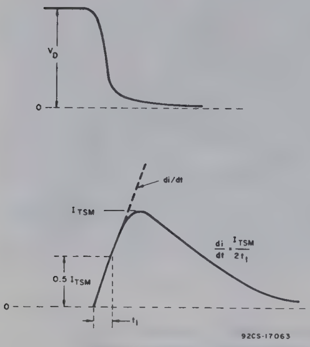


Fig. 13—Rate-of-change of on-state current with time (defining di/dt).

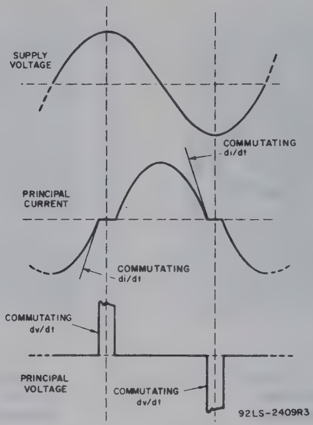


Fig. 14—Relationship between supply voltage and principal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

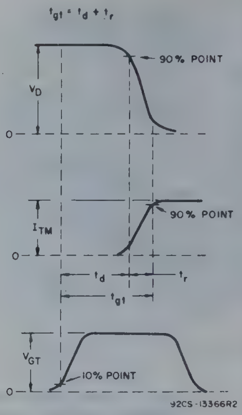


Fig. 15—Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).

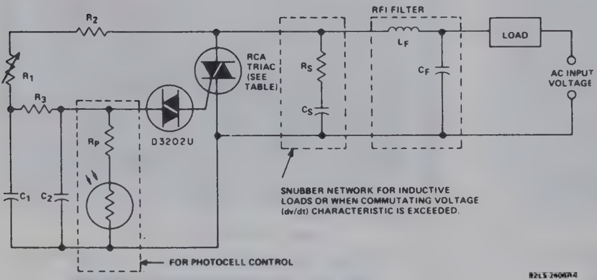

R_2
R_1
R_3
R_P
C_1
C_2
D3202U
RCA TRIAC (SEE TABLE)
R_S
C_S
RFI FILTER
L_F
C_F
LOAD
AC INPUT VOLTAGE
SNUBBER NETWORK FOR INDUCTIVE LOADS OR WHEN COMMUTATING VOLTAGE (dv/dt) CHARACTERISTIC IS EXCEEDED.
FOR PHOTOCELL CONTROL
92LS-2406R4

Fig. 16—Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.

AC INPUT VOLTAGE		120V 60Hz	240V 60Hz	240V 50Hz
C_1		0 1µF 200V	0.1µF 400V	0.1µF 400V
C_2		0.1µF 100V	0.1µF 100V	0.1µF 100V
R_1		100KΩ 1/2W	200KΩ 1W	250KΩ 1W
R_2		2.2KΩ 1/2W	3.3KΩ 1/2W	3.3KΩ 1/2W
R_3		15KΩ 1/2W	15KΩ 1/2W	15KΩ 1/2W
PHOTOCELL CONTROL	R_P	1.2KΩ 2W	1.2KΩ 2W	1.2KΩ 2W
SNUBBER NETWORK	C_S	0.1µF 200V	0.1µF 400V	0.1µF 400V
	R_S	100Ω 1/2W	100Ω 1/2W	100Ω 1/2W
RFI FILTER	C_F*	0.1µF 200V	0.1µF 400V	0.1µF 400V
	L_F*	100µH	200µH	200µH
RCA TRIACS		2N5567 2N5569 T4120B	2N5568 2N5570 T4120D	2N5568 2N5570 T4120D

*Typical values for lamp dimming circuits.

WARNING:
The RCA isolated-stud package thyristors should be handled with care. The ceramic portion of these thyristors contains BERYLLIUM OXIDE as a major ingredient. Do not crush, grind, or abrade these portions of the thyristors because the dust resulting from such action may be hazardous if inhaled.

TERMINAL CONNECTIONS

No.1—Gate
No.2—Main Terminal 1
No.3—Main Terminal 2

RCA
Solid State
Division

Thyristors
2N5754 – 2N5757
T2303 T2313 Series

MT2
MT1
Gate

2N5754 2N5756
2N5755 2N5757

T2303 Series

H-1380

T2313 Series

H-1468

2.5-A Silicon Triacs

Features:

- 25/40 mA I_{GT}
- Shorted-Emitter, Center-Gate Design
- Low Switching Losses
- Low On-State Voltage at High Current Levels

Package \ Voltage	100 V Types	200 V Types	400 V Types	600 V Types
Modified TO-5 (T2303 Series)	2N5754	2N5755	2N5756	2N5757
Modified TO-5 with Heat Rad. (T2313-Series)	T2313A (40684)	T2313B (40685)	T2313D (40686)	T2313M (40687)

Numbers in parentheses (e.g. 40684) are former RCA type numbers.

hese RCA triacs are gate-controlled full-wave silicon ac vitches that are designed to switch from an off-state to an n-state for either polarity of applied voltage with positive or egative gate triggering voltages.

The gate sensitivity of these triacs permits the use of economical transistorized control circuits and enhances their use in low-power phase control and load-switching applications.

IAXIMUM RATINGS, *Absolute-Maximum Values:*

or operation with sinusoidal supply voltage at frequencies p to 50/60 Hz and with resistive or inductive load.

		2N5754 T2313A	2N5755 T2313B	2N5756 T2313D	2N5757 T2313M	
EPETITIVE PEAK OFF-STATE VOLTAGE:●						
Gate open, T_J = –65 to 100°C	V_{DROM}	100	200	400	600	V
MS ON-STATE CURRENT (Conduction angle = 360°):	$I_{T(RMS)}$					
Case temperature T_C = 70°C (T2303-Series)		2.5				A
Ambient temperature T_A = 25°C (T2313-Series)		1.9				A
For other conditions		See Fig.2,3,4, & 5				
EAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}					
For one cycle of applied principal voltage, T_C = 70°C						
60 Hz (sinusoidal)		25				A
50 Hz (sinusoidal)		21				A
For more than one cycle of applied principal voltage		See Fig.6				
ATE OF CHANGE OF ON-STATE CURRENT:						
$V_{DM} = V_{DROM}$, I_{GT} = 50 mA, t_r = 0.1 μs (See Fig.13)	di/dt	100				A/μs
USING CURRENT (for Triac Protection):						
T_J = –65 to 100°C, t = 1.25 to 10 ms	I^2t	3				A^2s
EAK GATE-TRIGGER CURRENT:■						
For 1 μs max.	I_{GTM}	1				A
ATE POWER DISSIPATION:						
PEAK (For 10 μs max.)	P_{GM}	10				W
AVERAGE:	$P_{G(AV)}$					
T_C = 70°C		0.15				W
T_A = 25°C		0.05				W
EMPERATURE RANGE:▲						
Storage	T_{stg}	–65 to 150				°C
Operating (Case)	T_C	–65 to 100				°C
EAD TEMPERATURE (During soldering):						
At distance 1/32 in. (0.8 mm) from seating plane for 10 s max.	T_L	225				°C

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n accordance with JEDEC registration data format (JS-14, RDF-2 filed for the JEDEC (2N-Series) types.

or either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

■ For either polarity of gate voltage (V_G) with reference to main terminal 1.

▲ For temperature measurement reference point, see Dimensional Outline.

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC				SYMBOL	LIMITS			UNITS
					Min.	Typ.	Max.	
* **Peak Off-State Current:** ♦								
Gate Open, T_J = 100°C and V_{DROM} = Max. rated value				I_{DROM}	-	0.2	0.75	mA
Maximum On-State Voltage: ♦								
For i_T = 10 A (peak) and T_C = 25°C				V_{TM}	-	2.2	2.6	V
* For i_T = 3.5 A (peak) and T_C = 25°C					-	-	1.8	
DC Holding Current: ♦								
Gate Open, Initial principal current = 150 mA (DC), V_D = 12 V								
At T_C = 25°C				I_{HO}	-	6	35	mA
At T_C = -65°C					-	20	82*	
For other case temperatures					← See Fig.8. →			
Critical Rate of Rise of Commutation Voltage: ♦ For V_D = V_{DROM}, $I_{T(RMS)}$ = 2.5 A, commutating di/dt = 0.95 A/ms, gate unenergized, T_C = 70°C (See Fig. 13)				dv/dt	0.5	–	–	V/µs
* **Critical Rate-of-Rise of Off-State Voltage:** ♦ For V_D = V_{DROM}, exponential voltage rise, and gate open, T_C = 100°C				dv/dt	10	100	-	V/µs
DC Gate-Trigger Current: ♦ †	Mode	V_{MT2}	V_G					
For V_D = 12 V (DC),	I^+	positive	positive	I_{GT}	-	5	25	mA
R_L = 30Ω, and	III^-	negative	negative		-	5	25	
T_C = 25°C	I^-	positive	negative		-	10	40	
	III^+	negative	positive		-	10	40	
T_C = -65°C	I^+	positive	positive		-	30	60*	
	III^-	negative	negative		-	30	60*	
	I^-	positive	negative		-	40	100*	
	III^+	negative	positive		-	40	100*	
For other case temperatures					← See Fig.11. →			
DC Gate-Trigger Voltage: ♦ †								
For V_D = 12 V (DC) and R_L = 30 Ω								
At T_C = 25°C				V_{GT}	-	0.9	2.2	V
At T_C = -65°C					-	1.5	3*	
For other case temperatures					← See Fig.12. →			
* For v_D = V_{DROM} and R_L = 125Ω								
At T_C = 100°C					0.2	-	-	
Thermal Resistance:								
Steady State:								
* Junction-to-case				Rθ J-C	–	–	8.5	°C/W
Junction-to-ambinet (2N-series types only)				Rθ J-A	–	–	150	°C/W

♦ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

† For either polarity of gate voltage (V_G) with reference to main terminal 1.

* In accordance with JEDEC registration data format (JS-14, RDF-2).

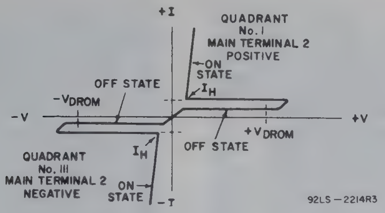


Fig. 1 — Principal voltage-current characteristic.

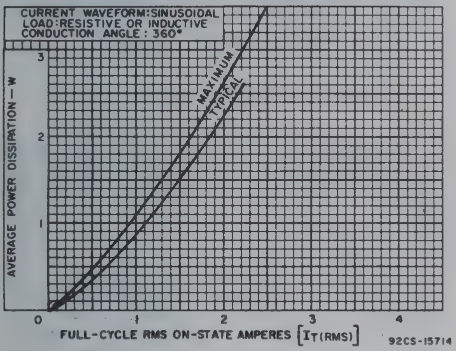


Fig. 2 — Power dissipation vs. on-state current.

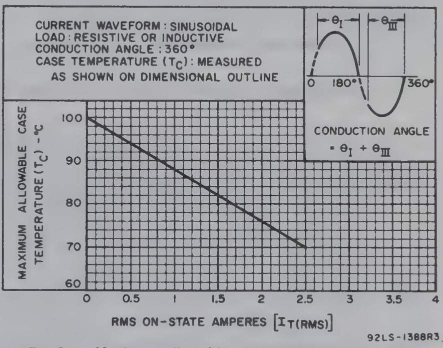


Fig. 3 — Maximum allowable case temperature vs. on-state current.

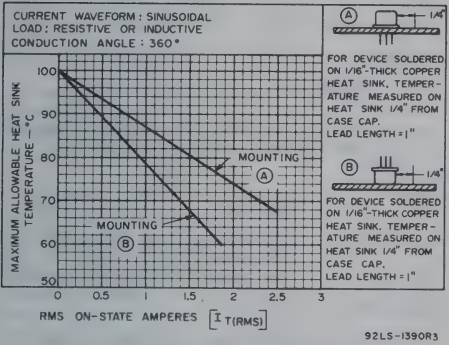


Fig. 4 — Maximum allowable heat-sink temperature vs. on-state current.

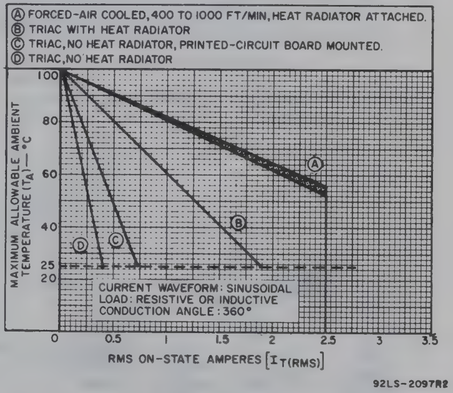


Fig. 5 — Maximum allowable ambient temperature vs. on-state current.

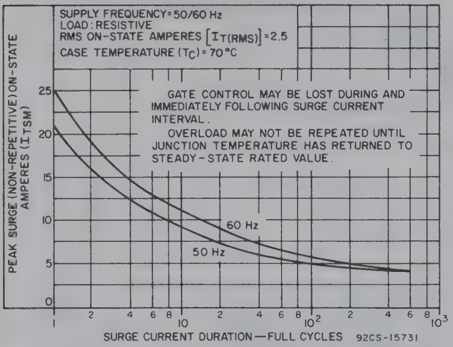


Fig. 6 — Peak surge on-state current vs. surge-current duration.

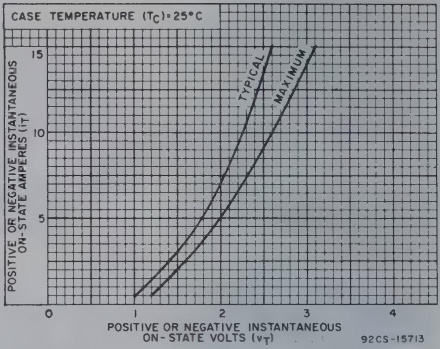


Fig. 7 — On-state current vs. on-state voltage.

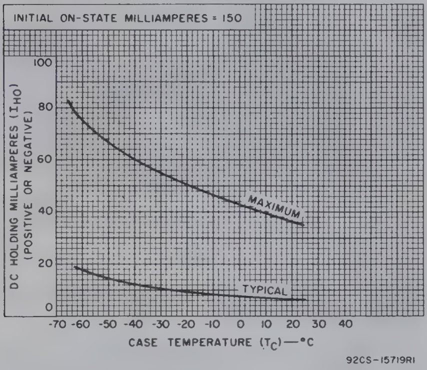


Fig. 8 — DC holding current (positive or negative) vs. case temperature.

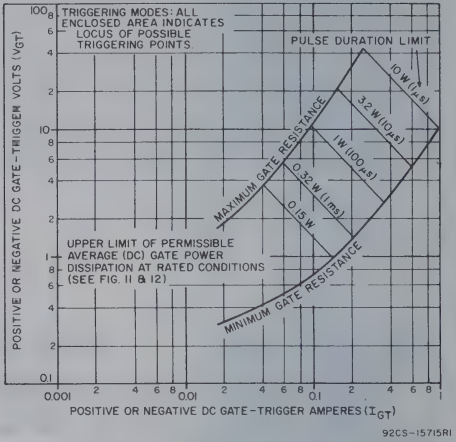
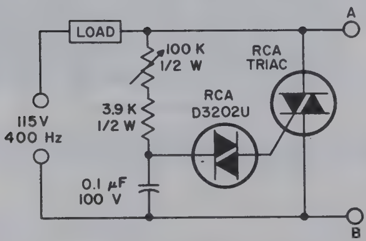
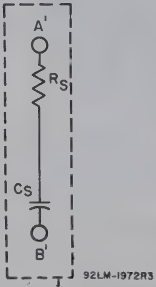


Fig. 9 — Gate trigger characteristics and limiting conditions for determination of permissible gate trigger pulses.



NOTE: For incandescent lamp loads which produce burnout current surges with I^2t values greater than 2.5 ampere^2 seconds, connect a 10-ohm resistor of appropriate power rating in series with the load. This rating can be determined as follows:

Power Rating of 10-ohm Resistor = 10(rms load current)^2



SNUBBER NETWORK FOR INDUCTIVE LOADS. CONNECT POINTS A' AND B' TO TERMINALS A AND B RESPECTIVELY.

AC INPUT VOLTAGE		120 V 60 Hz	240 V 60 Hz
SNUBBER NETWORK FOR 2.5 A (RMS)• INDUCTIVE LOAD	C_S	0.068 μF 200 V	0.075 μF 400 V
	R_S	2.2 kΩ ½ W	2.5 kΩ ½ W
RCA TRIACS		2N5755 T2313B	2N5756 T2313D

•For other RMS Current values refer to RCA Application Note AN-4745.

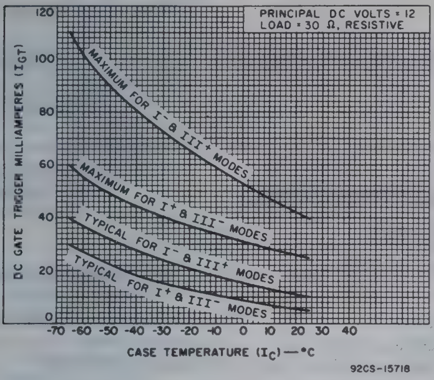


Fig. 11 – DC gate-trigger current vs. case temperature.

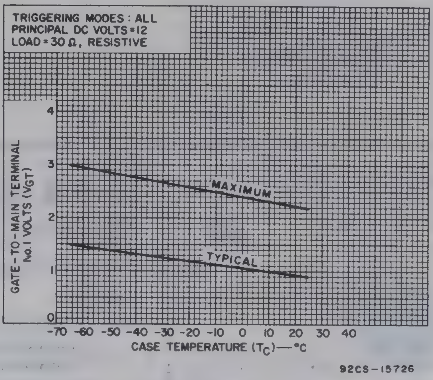


Fig. 12 – DC gate-trigger voltage vs. case temperature.

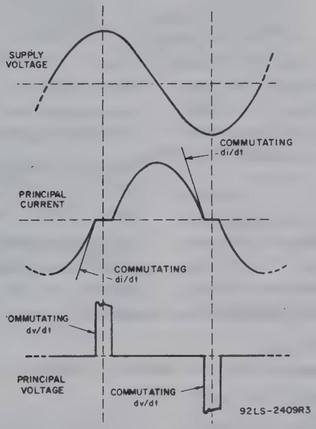

SUPPLY VOLTAGE
COMMUTATING -di/dt
PRINCIPAL CURRENT
COMMUTATING -di/dt
COMMUTATING dv/dt
PRINCIPAL VOLTAGE
COMMUTATING dv/dt
92LS-2409R3

Fig. 13– Relationship between supply voltage and principle current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

TERMINAL CONNECTIONS

For Types 2N5754, 2N5755, 2N5756, 2N5657

Lead No. 1 – Main terminal 1
Lead No. 2 – Gate
Case, Lead No. 3 – Main terminal 2

For T2313 Series

Lead No. 1 – Main terminal 1
Lead No. 2 – Gate
Heat Rad., Lead No. 3 – Main terminal 2

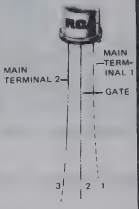
RCA
Solid State Division

Thyristors

T2300 T2302 T2310 T2312 Series

T2310 Series
T2312 Series

H-1468



T2300 Series
T2302 Series

H-1380V1

2.5-A Sensitive-Gate Silicon Triacs

For Low-Power Phase-Control and Load-Switching Applications

Features:

- **Very High Gate Sensitivity**
  3 mA max. for T2300 and T2310 series
  10 mA max. for T2302 and T2312 series
- **3-Lead Package for Printed Circuit Board Applications**
- **Shorted Emitter Design**

Package \ Voltage	100 V Types	200 V Types	400 V Types
Mod. TO-5	T2300A (40525)	T2300B (40526)	T2300D (40527)
Mod. TO-5	T2302A (40528)	T2302B (40529)	T2302D (40530)
TO-5 with Radiator	T2310A (40531)	T2310B (40532)	T2310D (40533)
TO-5 with Radiator	T2312A (40534)	T2312B (40535)	T2312D (40536)

Numbers in parentheses are former RCA type numbers.

RCA T2300-, T2302-, T2310-, and T2312-series triacs are gate-controlled full-wave ac silicon switches. They are designed to switch from a blocking state to a conducting state for either polarity of applied voltage with positive or negative gate triggering.

The T2302 series has higher dv/dt capability and higher gate trigger current requirements than the T2300 series. The gate sensitivity of these triacs permits the use of economical transistorized and IC control circuits and enhances their use in low-power phase control and load-switching applications.

The T2300 series has rms on-state current ratings of 2.5 amperes at a case temperature of +60°C while the T2302 series has the same ratings at a case temperature of +70°C.

The repetitive peak off-state voltage rating for T2300A and T2302A is 100 volts; for T2300B and T2302B, 200 volts; and for T2300D and T2302D, 400 volts.

The T2310 and T2312 series are the same as the T2300 and T2302 series, respectively, but have factory-attached heat-radiators and are intended for printed-circuit-board applications.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with 50/60-Hz, Sinusoidal Supply Voltage and Resistive or Inductive Load

REPETITIVE PEAK OFF-STATE VOLTAGE♦ (Gate Open):	V_{DROM}		
T_J = −40°C to +90°C: T2300A, T2310A		100	V
T2300B, T2310B		200	V
T2300D, T2310D		400	V
T_J = −40°C to +100°C: T2302A, T2312A		100	V
T2302B, T2312B		200	V
T2302D, T2312D		400	V
RMS ON-STATE CURRENT (Conduction Angle = 360°):	$I_{T(RMS)}$		
T_C = 60°C: T2300 series		2.5	A
T_C = 70°C: T2302 series		2.5	A
T_A = 25°C: T2300 series		0.35	A
T2302 series		0.40	A
For other conditions		See Figs. 2, 3, 4 & 5	
For heat-radiator types		See Figs. 6 & 7	
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}		
For one full cycle of applied principal voltage, T_C as above			
60 Hz sinusoidal		25	A
50 Hz sinusoidal		21	A
For more than one full cycle of applied voltage		See Fig. 8	
RATE OF CHANGE OF ON-STATE CURRENT:			
$V_{DM} = V_{DROM}$, I_{GT} = 50 mA, t_r = 0.1 μs (See Fig. 19)	di/dt	100	A/μs
FUSING CURRENT (for Triac Protection):			
T_J = −65 to 100°C, t = 1.25 to 10 ms	I^2t	3	A^2s

MAXIMUM RATINGS (Cont'd.).

PEAK GATE-TRIGGER CURRENT†:			
For 1 µs max.	I_{GTM}	0.5	A
GATE POWER DISSIPATION†:			
Peak (For 1 µs max.)	P_{GM}	10	W
Average: T_C = 60°C	$P_{G(AV)}$	0.15	W
T_A = 25°C		0.05	W
TEMPERATURE RANGE‡:			
Storage		−40 to +150	°C
Operating (case): T2300 Series		−40 to +90	°C
T2302 Series		−40 to +100	°C
T2310, T2312 Series (From −40°C) Upper limits		See Figs. 6 & 7	
LEAD TEMPERATURE:			
During soldering, terminal temperature at a distance ≥ 1/6 in. (1.58 mm) from the case for 10 s		225	°C

♦ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

† For either polarity of gate voltage (V_G) with reference to main terminal 1.

‡ For information on the reference point of temperature measurement see *Dimensional Outlines.*

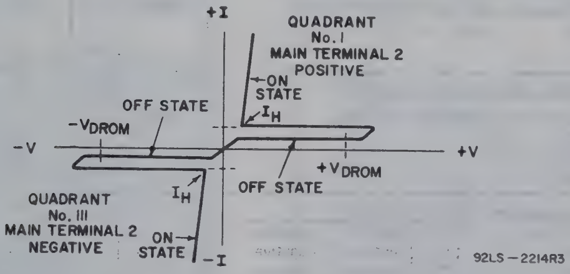

+I
QUADRANT
No. I
MAIN TERMINAL 2
POSITIVE
ON
STATE
I_H
OFF STATE
$-V_{DROM}$
−V
+V
$+V_{DROM}$
OFF STATE
QUADRANT
No. III
MAIN TERMINAL 2
NEGATIVE
I_H
ON
STATE
−I
92LS—2214R3

Fig. 1 — Principal voltage-current characteristics.

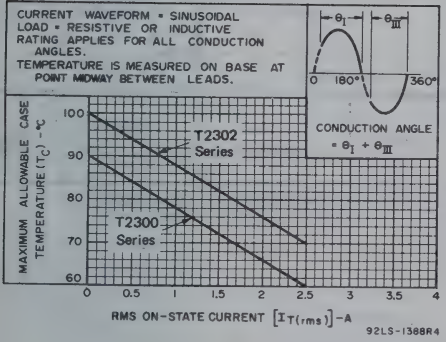


Fig. 2 — Conduction rating chart (case temperature) for T2300 and T2302 series.

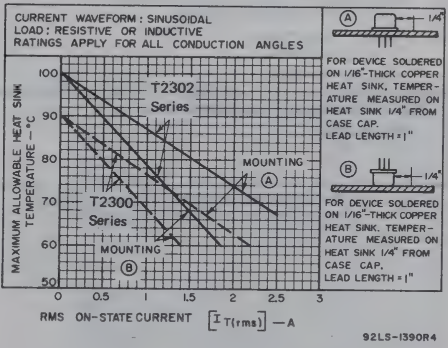


Fig. 3 — Conduction characteristics as a function of mounting method for T2300 and T2302 series.

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	Mode	V_{MT2}	V_G	SYMBOL	LIMITS						UNITS
					T2300 Series T2310 Series			T2302 Series T2312 Series			
					MIN.	TYP.	MAX	MIN.	TYP.	MAX	
Peak Off-State Current: ♠											
Gate Open and V_{DROM} = Max. rated value											
At T_j = +100° C				I_{DROM}	–	–	–	–	0.2	0.75	mA
At T_j = +90° C					–	0.2	0.75	–	–	–	
Maximum On-State Voltage:♠				V_{TM}							
For i_T = 10 A (peak) and T_C = 25° C					–	1.7	2.2	–	1.7	2.2	V
DC Holding Current:♠											
Gate Open, Initial principal current = 150 mA (DC), V_D =12											
At T_C = 25° C				I_{HO}	–	2	5	–	6.5	15	mA
For other case temperatures					See Fig. 14			See Fig. 15			
Critical Rate of Rise of Commutation Voltage:♠											
For V_D = V_{DROM}, $I_{T(RMS)}$ = 2.5 A, commutating di/dt = 0.95 A/µs, gate unenergized, (See Fig. 20),				dv/dt							
T_C = 100°C					–	–	–	0.5	–	–	V/ µs
T_C = 90°C					0.5	–	–	–	–	–	V/ µs
Critical Rate-of-Rise of Off-State Voltage:♠											
For V_D = V_{DROM}, exponential voltage rise, and gate open				dv/dt							V/µs
At T_C = +100° C					–	–	–	6	10	–	
At T_C = +90° C					3	5	–	–	–	–	
DC Gate-Trigger Current:♠†	Mode	V_{MT2}	V_G								
For V_D = 12 V (DC),	I^+	positive	positive		–	1	3	–	3.5	10	
R_L = 30 Ω, and	III^-	negative	negative	I_{GT}	–	1	3	–	3.5	10	mA
T_C = 25° C	I^-	positive	negative		–	2	3	–	7	10	
	III^+	negative	positive		–	2	3	–	7	10	
For other case temperatures					See Fig. 12			See Fig. 13			
DC Gate-Trigger Voltage:♠†											
For V_D = 12 V (DC) and R_L = 30 Ω											
At T_C = 25° C				V_{GT}	–	1	2.2	–	1	2.2	V
For other case temperatures					See Fig. 11			See Fig. 11			
For v_D = V_{DROM} and R_L = 125 Ω											
At T_C = 100° C					–	–	–	0.15	–	–	
At T_C = +90° C					0.15	–	–	–	–	–	
Thermal Resistance, Junction-to-Case:											
Steady-State				$R_{\theta JC}$	8.5 (max.) (T2300 series)			8.5 (max.) (T2302 series)			°C/W

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

† For either polarity of gate voltage (V_G) with reference to main terminal 1.

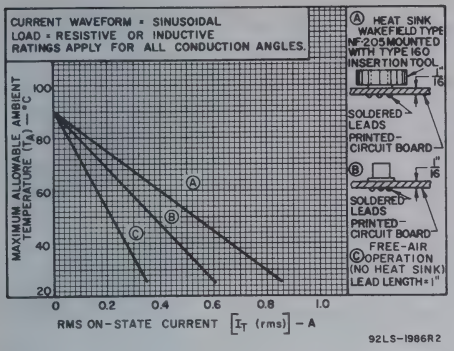


Fig. 4 — Conduction rating chart (ambient temperature) for T2300 series.

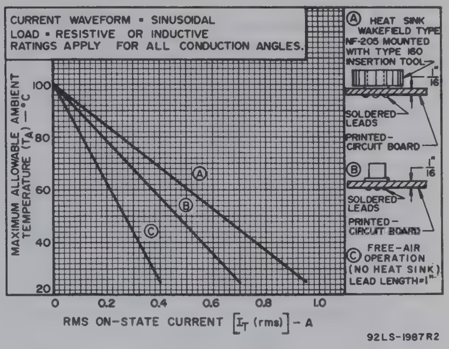


Fig. 5 — Conduction rating chart (ambient temperature) for T2302 series.

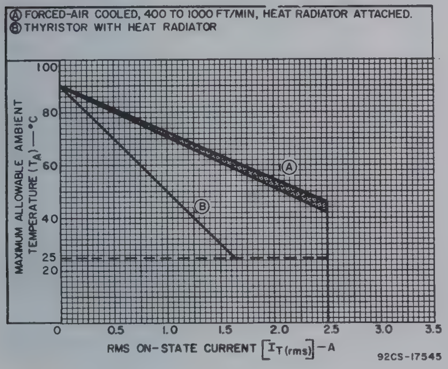


Fig. 6 — Conduction rating chart (ambient temperature) for T2310 series.

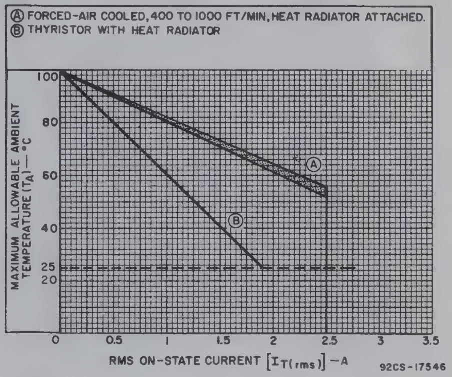


Fig. 7 — Conduction rating chart (ambient temperature) for T2312 series.

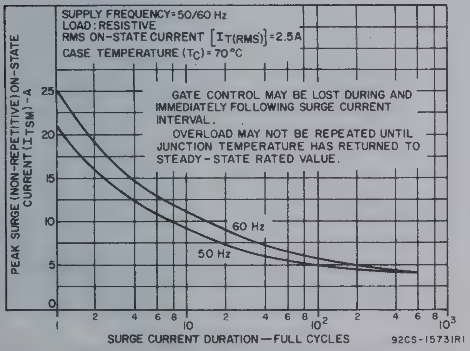


Fig. 8 — Peak surge on-state current vs. surge-current duration for all types.

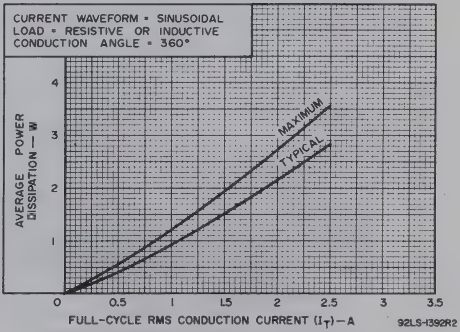


Fig. 9 — Power dissipation curves for all types.

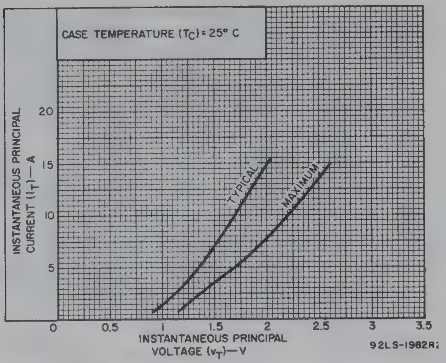


Fig. 10 — On-state characteristics for either direction of principal current for all types.

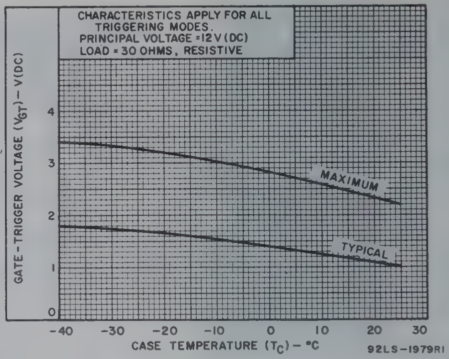


Fig. 11 — DC Gate-trigger voltage characteristics for all types.

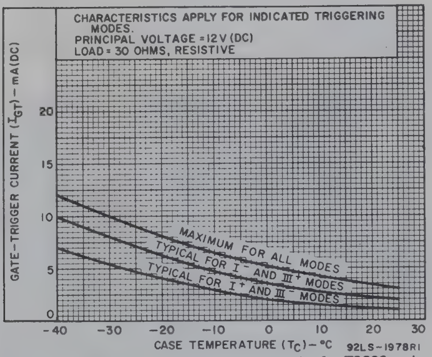


Fig. 12 — DC gate-trigger current characteristics for T2300 and T2310 series.

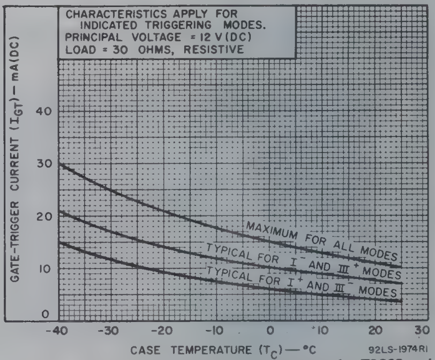


Fig. 13 — DC gate-trigger current characteristics for T2302 and T2312 series.

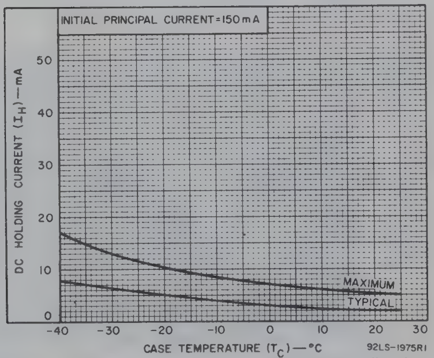


Fig. 14 — DC holding current characteristics for either direction of principal current for T2300 and T2310 series.

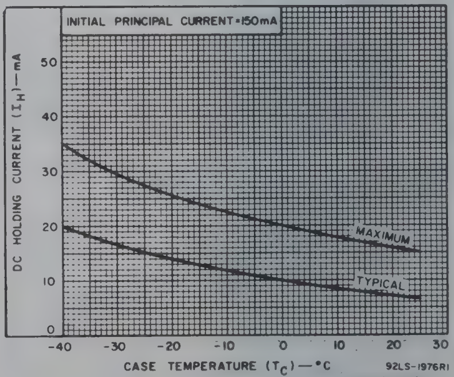


Fig. 15 — DC holding current characteristics for either direction of prinicpal current for T2302 and T2312 series.

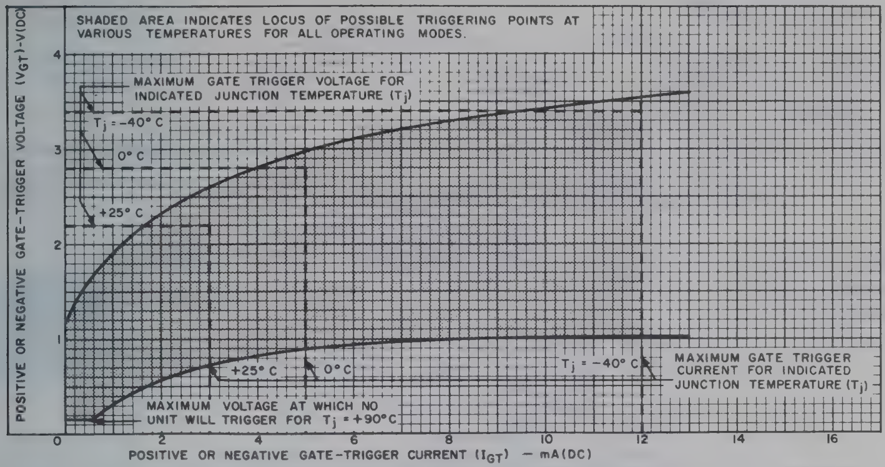


Fig. 16 — Gate characteristics for T2300 and T2310 series.

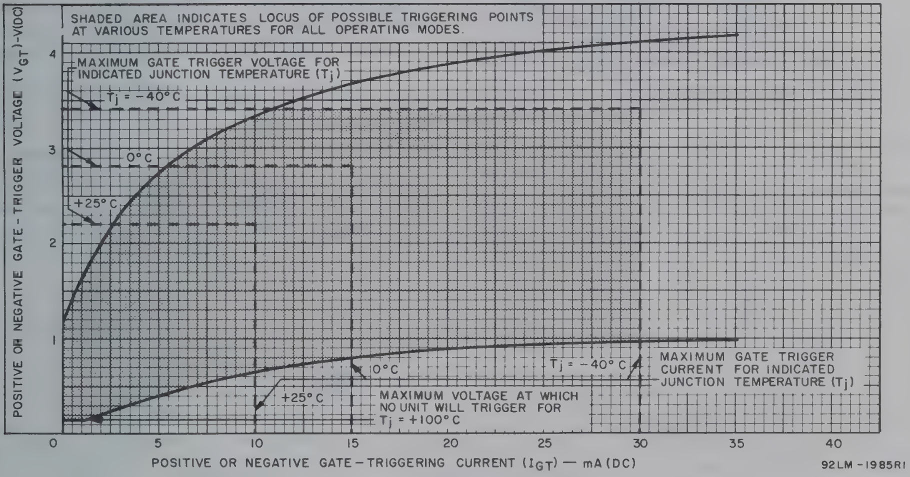
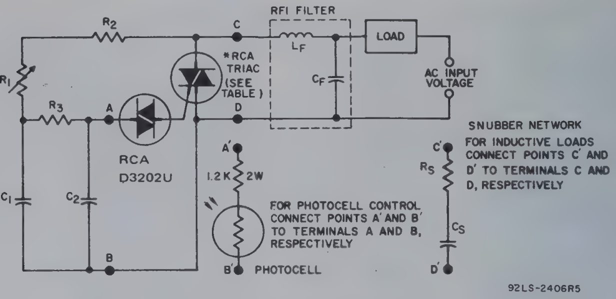


Fig. 17 — Gate characteristics for T2302 and T2312 series.

TERMINAL CONNECTIONS

For T2300 and T2302 series	For T2310 and T2312 series
Lead No. 1 — Main terminal 1	Lead No. 1 — Main terminal 1
Lead No. 2 — Gate	Lead No. 2 — Gate
Case, Lead No. 3 — Main terminal 2	Heat Rad., Lead No. 3 — Main terminal 2


RFI FILTER
R2
C
LF
CF
LOAD
AC INPUT VOLTAGE
*RCA TRIAC (SEE TABLE)
D
R1
R3
A
RCA D3202U
A'
1.2 K
2W
C1
C2
B
B'
PHOTOCELL
FOR PHOTOCELL CONTROL CONNECT POINTS A' AND B' TO TERMINALS A AND B, RESPECTIVELY
SNUBBER NETWORK
FOR INDUCTIVE LOADS CONNECT POINTS C' AND D' TO TERMINALS C AND D, RESPECTIVELY
C'
RS
CS
D'
92LS-2406R5

NOTE: For incandescent lamp loads which produce burnout current surges with I^2t values greater than 2.5 ampere^2 seconds, connect a 10-ohm resistor of appropriate wattage rating in series with the load. The appropriate wattage rating can be determined as follows:

Power Rating of
10-ohm Resistor = 10 x (rms load current)^2

AC INPUT VOLTAGE	C_1	C_2	R_1	R_2	R_3	RFI FILTER		SNUBBER NETWORK		RCA TYPES
						L_F * (typ.)	C_F * (typ.)	C_S	R_S	
120V 60Hz	0.1µF 200V	0.1µF 100V	100KΩ ½W	2.2KΩ ½W	15KΩ ½W	100µH	0.1µF 200V	0.068µF 200V	2.2KΩ ½W	T2300B,T2310B T2302B,T2312B
240V 60Hz	0.1µF 400V	0.1µF 100V	250KΩ 1W	3.3KΩ ½W	15KΩ ½W	200µH	0.1µF 400V	0.075µF 400V	2.5KΩ ½W	T2300D,T2302D T2310D,T2312D

*Typical values for lamp dimming circuits

Fig. 18 — Typical phase-control circuit for lamp dimming, heat controls, and universal motor speed controls.

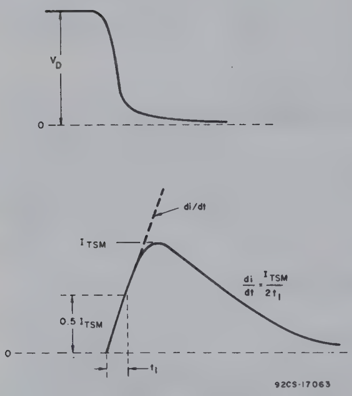


Fig. 19— Rate of change of on-state current with time (defining di/dt).

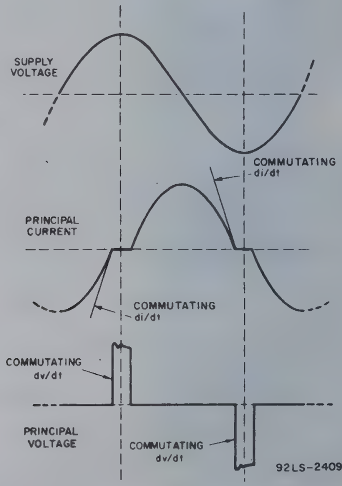
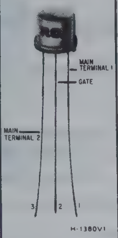


Fig. 20— Relationship between supply voltage and principle current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

RCA
Solid State
Division

Thyristors
T2301 T2311 Series

T2311 Series



T2301 Series

2.5-Ampere Sensitive-Gate Silicon Triacs

For Low-Power Phase-Control and Load-Switching Applications

Features:

- Very high gate sensitivity – 4 mA
- Heat-radiator package for printed circuit board applications
- Small size – suitable for remote switching applications
- Shorted emitter design

Package \ Voltage	100 V Types	200 V Types	400 V Types
Modified TO-5	T2301A (40766)	T2301B (40691)	T2301D (40692)
Mod. TO-5 with Heat Radiator	T2311A (40767)	T2311B (40761)	T2311D (40762)

Numbers in parentheses are former RCA type numbers.

RCA T2301- and T2311-series triacs are gate-controlled full-wave ac switches. These devices are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

The high gate sensitivity of these triacs permits the use of economical transistorized or integrated control circuits and enhances their use in low-power phase control and load-switching applications.

The T2301-series triacs are supplied in a compact package (similar to JEDEC TO-5) and have an RMS on-state current rating of 2.5 A and repetitive peak off-state voltage ratings of 100, 200, and 400 volts.

The T2311-series triacs are the same as the T2301-series triacs, but have factory-attached heat-radiators and are intended for printed-circuit board applications.

With the exception of the characteristics listed below, data shown for the T2300 series in bulletin File No. 470 are applicable to the T2301 series.

Data shown for the T2310 series in bulletin File No. 470 are applicable to the T2311 series.

For data on additional RCA sensitive-gate triacs, refer to bulletin File No. 470.

ELECTRICAL CHARACTERISTICS:

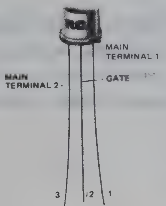
Characteristic				Limits			Units
DC Gate-Trigger Current, I_{GT}	Mode	V_{MT2}	V_G	Min.	Typ.	Max.	
For v_D = 12 V (DC), R_L = 30Ω, and T_C = 25° C	I^+	positive	positive	–	1	4	mA
	III^-	negative	negative	–	1	4	
	I^-	positive	negative	–	2	4	
	III^+	negative	positive	–	2	4	

RCA
Solid State Division

Thyristors
T2304 T2305 Series

400-Hz,0.5-A Sensitive-Gate Silicon Triacs

For Control-Systems Application in Airborne and Ground-Support Type Equipment



Modified JEDEC TO-5

H-1380V1

Features:

- **High gate sensitivity, I_{GT} = 10/40 mA max.**
- **di/dt capability = 100 A/µs**
- **Commutating dv/dt capability characterized at 400 Hz**
- **Shorted-Emitter Design**

Voltage / Package	200 V Types	400 V Types
Modified TO-5	T2304B (40769)	T2304D (40770)
Modified TO-5	T2305B (40771)	T2305D (40772)

Numbers in parentheses are former RCA type numbers.

RCA T2304- and T2305-series triacs are gate-controlled full-wave silicon ac switches. They are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

These triacs are intended for operation up to 400 Hz with resistive or inductive loads and nominal line voltages of 115 and 208 V RMS sine wave and repetitive peak off-stage voltages of 200 V and 400 V.

The high gate sensitivity of these triacs permits the use of economical transistorized or integrated control circuits and enhances their use in low-power phase control and load-switching applications.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

For Operation with Sinusoidal Supply Voltage at Frequencies up to 400 Hz and with Resistive or Inductive Load.

		T2304B T2305B	T2304D T2305D	
REPETITIVE PEAK OFF-STATE VOLTAGE:*				
Gate open, T_J = -50 to 100°C	V_{DROM}	200	400	V
RMS ON-STATE CURRENT (Conduction angle = 360°):	$I_{T(RMS)}$			
Case temperature (T_C) = 90°C		0.5		A
Ambient temperature (T_A) = 25°C, without heat sink		0.4		A
For other conditions		*See Figs. 3 & 4*		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}			
For one cycle of applied principal voltage, T_C = 90°C				
400 Hz (sinusoidal)		50		A
60 Hz (sinusoidal)		25		A
50 Hz (sinusoidal)		21		A
For more than one cycle of applied principal voltage		*See Fig. 5*		
RATE-OF-CHANGE OF ON-STATE CURRENT:	di/dt			
V_{DM} = V_{DROM}, I_{GT} = 60 mA, t_r = 0.1 µs (*See Fig. 14*)		100		A/µs
FUSING CURRENT (for triac protection):				
T_J = -50 to 100°C, t = 1.25 to 10 ms	I^2t	2		A^2s
PEAK GATE-TRIGGER CURRENT:■	I_{GTM}			
For 1 µs (max.) (*See Fig. 10*)		1		A
GATE POWER DISSIPATION:				
PEAK (For 1 µs max., (*See Fig. 10*)	P_{GM}	10		W
AVERAGE (At T_C = 60°C)	$P_{G(AV)}$	0.15		W
(At T_A = 25°C, without heat sink)	$P_{G(AV)}$	0.05		W
TEMPERATURE RANGE:▲				
Storage	T_{stg}	-50 to 150		°C
Operating (Case)	T_C	-50 to 100		°C
LEAD TEMPERATURE (During soldering):				
At distances ≥ 1/16 in. (1.58 mm) from the case for 10 s max.	T_L	225		°C

---

* For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

■ For either polarity of gate voltage (V_G) with reference to main terminal 1.

▲ For temperature measurement reference point, see Dimensional Outline.

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	SYMBOL	LIMITS						UNITS
		T2304 Series			T2305 Series			
		Min.	Typ.	Max.	Min.	Typ.	Max.	
Peak Off-State Current:♠ Gate open, $T_J = 100^oC$, V_{DROM} = Max. rated value	I_{DROM}	-	0.2	0.75	-	0.2	0.75	mA
Maximum On-State Voltage:♠ For i_T = 10 A (peak), $T_C = 25^oC$	V_{TM}	-	1.7	2.2	-	1.7	2.2	V
DC Holding Current:♠ Gate open, Initial principal current = 150 mA (DC), v_D = 12 V, $T_C = 25^oC$	I_{HO}	-	7	15	-	15	30	mA
For other case temperatures		See Figs. 8 & 9						
Critical Rate-of-Rise of Commutation Voltage:♠ For $v_D = V_{DROM}$, $I_{T(RMS)}$ = 0.5 A, commutating di/dt = 1.8 A/ms, gate unenergized, $T_C = 90^oC$ (See Fig. 15)	dv/dt	1	4	-	1	4	-	V/µs
Critical Rate-of-Rise of Off-Stage Voltage:♠ For $v_D = V_{DROM}$, exponentail voltage rise, gate open, $T_C = 100^oC$	dv/dt	10	100	-	10	100	-	V/µs
DC Gate-Trigger Current:♠ Mode I^+, V_{MT2} positive, V_G positive For v_D = 12 V (DC),	I_{GT}	-	3.5	10	-	5	25	mA
$R_L = 30\ \Omega$ — Mode III^-, V_{MT2} negative, V_G negative		-	3.5	10	-	5	25	
$T_C = 25^oC$ — Mode I^-, V_{MT2} positive, V_G negative		-	7	10	-	10	40	
Mode III^+, V_{MT2} negative, V_G positive		-	7	10	-	10	40	
For other case temperatures		See Figs. 11 & 12						
DC Gate-Trigger Voltage:♠† For v_D = 12 V (DC), $R_L = 30\Omega$, $T_C = 25^oC$	V_{GT}	-	1	2.2	-	1	2.2	V
For other case temperatures		See Fig. 13						
For $v_D = V_{DROM}$, $R_L = 125\Omega$, $T_C = 100^oC$		0.15	-	-	0.15	-	-	
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For $v_D = V_{DROM}$, I_{GT} = 60 mA, t_r = 0.1 µs, i_T = 10 A (peak), $T_C = 25^oC$ (See Fig. 16)	t_{gt}	-	1.8	-	2.5	1.8	2.5	µs
Thermal Resistance, Junction-to-Case:	θ_{J-C}	-	-	8.5	-	-	8.5	°C/W

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

† For either polarity of gate voltage (V_G) with reference to main terminal 1.

The following data are applicable to all triacs except as noted.

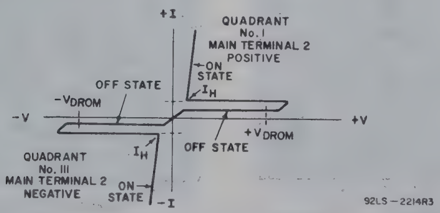


Fig. 1 — Principal voltage-current characteristic.

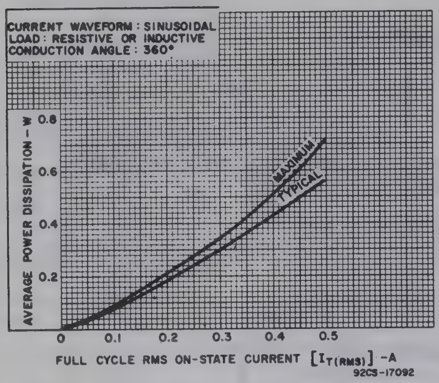


Fig. 2 — Power dissipation vs. on-state current.

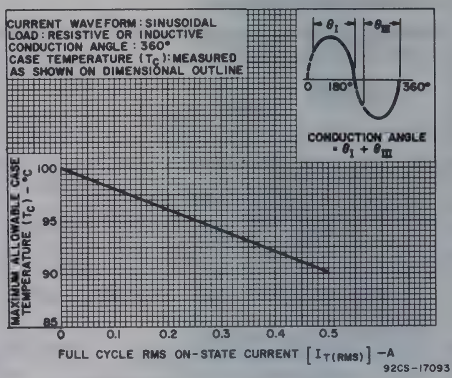


Fig. 3 — Maximum allowable case temperature vs. on-state current.

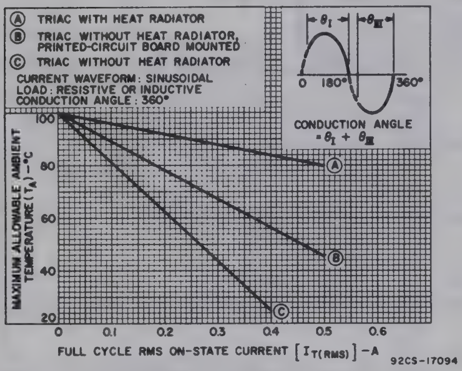


Fig. 4 — Maximum allowable ambient temperature vs. on-state current for the package/mounting options of these triacs.

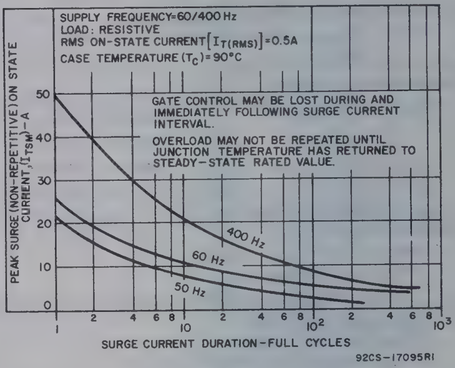


Fig. 5 — Peak surge on-stage current vs. surge-current duration.

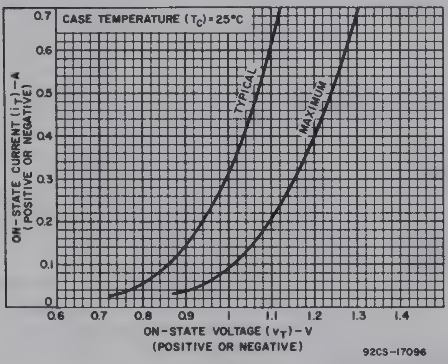


Fig. 6 — On-state current vs. on-state voltage (steady-state condition).

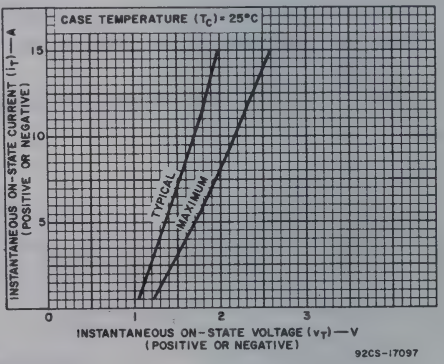


Fig. 7 — On-state current vs. on-state voltage (surge condition).

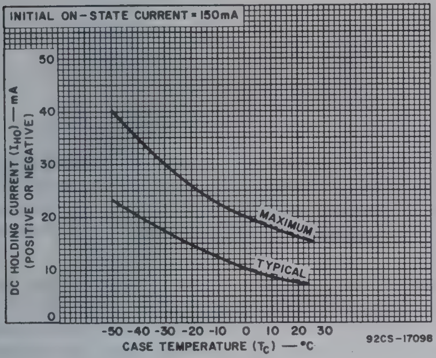


Fig. 8 — DC holding current vs. case temperature for T2304 series.

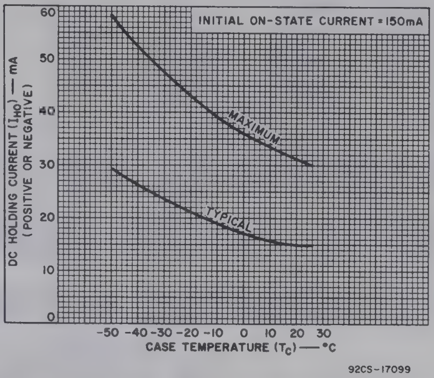


Fig. 9 — DC holding current vs. case temperature for T2305 series.

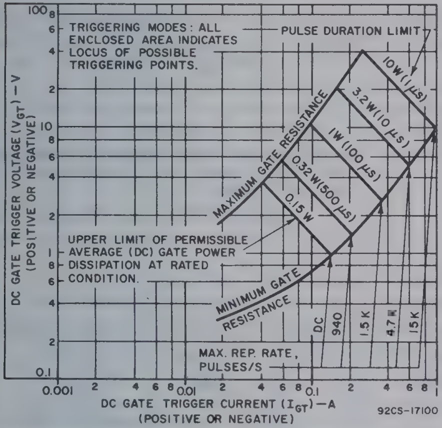


Fig. 10 — Gate trigger characteristics and limiting conditions for determination of permissible gate trigger pulses.

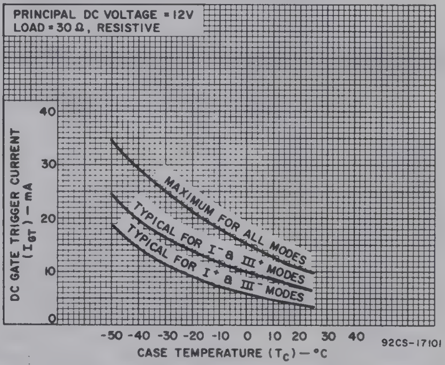


Fig. 11 — DC gate-trigger current vs. case temperature for T2304 series.

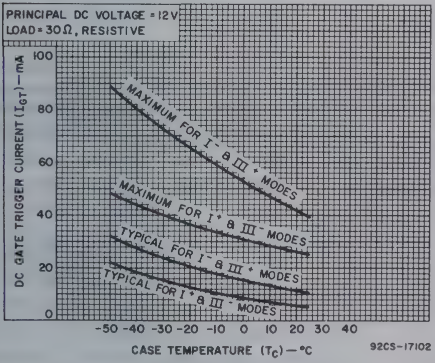


Fig. 12 — DC gate-trigger current vs. case temperature for T2305 series.

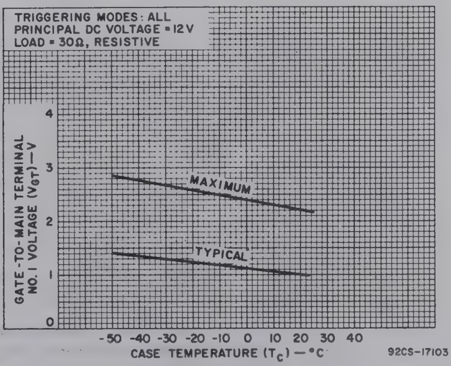


Fig. 13 — DC gate-trigger voltage vs. case temperature.

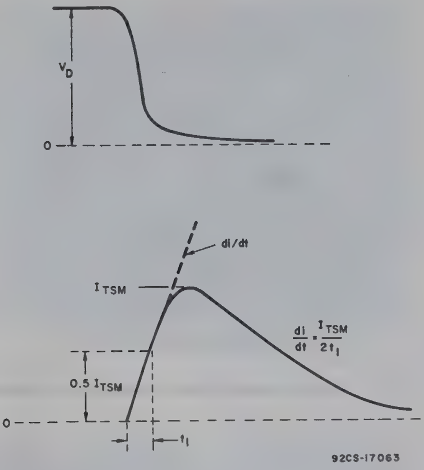


Fig. 14 — Rate-of-change of on-state current with time (defining di/dt).

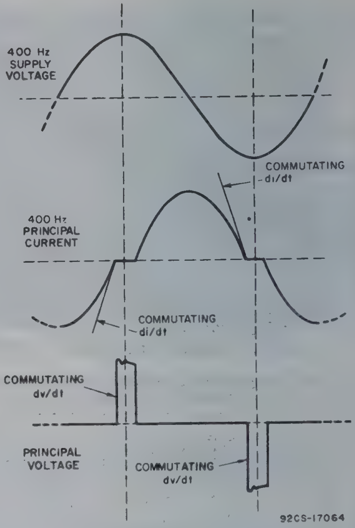


Fig. 15 — Relationship between supply voltage and principal curren (inductive load) showing reference points for definition o commutating voltage (dv/dt).

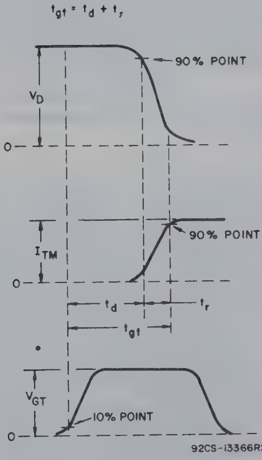
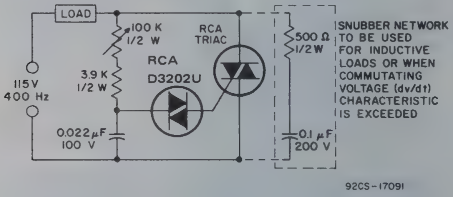


Fig. 16 — Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).


LOAD
100 K 1/2 W
RCA TRIAC
RCA D3202U
3.9 K 1/2 W
115 V 400 Hz
0.022 μF 100 V
500 Ω 1/2 W
0.1 μF 200 V
SNUBBER NETWORK TO BE USED FOR INDUCTIVE LOADS OR WHEN COMMUTATING VOLTAGE (dv/dt) CHARACTERISTIC IS EXCEEDED
92CS-17091

NOTE: For incandescent lamp loads which produce burnout current surges with I^2t values greater than 2.5 ampere^2 seconds, connect a 10 – ohm resistor of appropriate power rating in series with the load. This rating can be determined as follows:

Power Rating of 10-ohm Resistor = 10 (rms load current)^2

Fig. 17 — Typical phase-control circuit for operation at 400 Hz.

TERMINAL CONNECTIONS

Lead No. 1 - Main terminal 1
Lead No. 2 - Gate
Case, Lead No. 3 - Main terminal 2

RCA
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Thyristors

T2306 T2316 T2706 T2806
T2716 T4106 T4107 T4116
T4117 T4706 T6406 T6407
T6416 T6417

Series

2.5–40-A, 100–600-V SILICON TRIACS DESIGNED FOR USE WITH IC ZERO-VOLTAGE SWITCHES AS TRIGGERING CIRCUITS

For Power-Control and Switching Applications at Frequencies of 50 to 60 Hz

These triacs are gate-controlled full-wave ac switches. They are intended for ac load-control applications such as heating controls (proportional or on-off); lamp switching, motor switching, and a wide variety of power-control applications.

The RCA CA3058, CA3059, and CA3079 are monolithic silicon IC zero-voltage switches designed for direct operation from the ac line. They can drive the triac gate directly and provide the gating signal at zero-voltage crossings for minimum radio-frequency interference.

These triacs have gate characteristics which assure that the zero-voltage switch can supply sufficient drive current to trigger them over the operating-temperature range from -40°C to +85°C. Ratings within this group of triacs range from 2.5 to 40 amperes rms on-state current, with repetitive off-state voltages available from 100 to 600 volts; and they employ a wide variety of packages.

RATINGS AND CHARACTERISTICS

Type No.	Former RCA Type No.	Rep. Peak Off-State Voltage V_{DROM} (V)	RMS On-State Current $I_{T(RMS)}$ (A)	at Case Temp. (°C)	Typ. DC Holding Current at 25°C, I_{HO} (mA)	Max. DC Gate Trigger Current and Voltage at 25°C▲ I+ I_{GT} (mA)	I+ V_{GT} (V)	III+ I_{GT} (mA)	III+ V_{GT} (V)	Package	For Additional Data, Refer to Bulletin File No.*
T2316A	40693	100	2.5	70	6	45	1.5	45	1.5	Mod. TO-5 on Heat Radiator	414
T2316B	40694	200	2.5	70	6	45	1.5	45	1.5	"	414
T2316D	40695	400	2.5	70	6	45	1.5	45	1.5	"	414
T2306A	40696	100	2.5	70	6	45	1.5	45	1.5	Mod. TO-5	414
T2306B	40697	200	2.5	70	6	45	1.5	45	1.5	"	414
T2306D	40698	400	2.5	70	6	45	1.5	45	1.5	Mod. TO-5	414
T6406B	40699	200	40	70	25	45	1.5	45	1.5	Press-fit	593
T6406D	40700	400	40	70	25	45	1.5	45	1.5	"	593
T6406M	40701	600	40	70	25	45	1.5	45	1.5	"	593
T6416B	40702	200	40	65	25	45	1.5	45	1.5	Stud	593
T6416D	40703	400	40	65	25	45	1.5	45	1.5	Stud	593
T6416M	40704	600	40	65	25	45	1.5	45	1.5	"	593
T6407B	40705	200	30	65	25	45	1.5	45	1.5	Press-fit	459
T6407D	40706	400	30	65	25	45	1.5	45	1.5	"	459
T6417B	40707	200	30	60	25	45	1.5	45	1.5	Stud	459

RATINGS AND CHARACTERISTICS (Cont'd.)

Type No.	Former RCA Type No.	Rep. Peak Off-State Voltage V_{DROM} (V)	RMS On-State Current $I_{T(RMS)}$ (A)	at Case Temp. (°C)	Typ. DC Holding Current at 25°C, I_{HO} (mA)	Max. DC Gate Trigger Current and Voltage at 25°C▲				Package	For Additional Data, Refer to Bulletin File No.*
						I^+		III^+			
						I_{GT} (mA)	V_{GT} (V)	I_{GT} (mA)	V_{GT} (V)		
T6417D	40708	400	30	60	25	45	1.5	45	1.5	Stud	459
T6407M	40709	600	30	65	25	45	1.5	45	1.5	Press-fit	459
T6417M	40710	600	30	60	25	45	1.5	45	1.5	Stud	459
T4106B	40711	200	15	80	20	45	1.5	45	1.5	Press-fit	458
T4106D	40712	400	15	80	20	45	1.5	45	1.5	"	458
T4116B	40713	200	15	80	20	45	1.5	45	1.5	Stud	458
T4116D	40714	400	15	80	20	45	1.5	45	1.5	"	458
T4706B	40715	200	15	70	15	45	1.5	45	1.5	TO-66	300
T4706D	40716	400	15	70	15	45	1.5	45	1.5	"	300
T4107B	40717	200	10	85	15	45	1.5	45	1.5	Press-fit	457
T4107D	40718	400	10	85	15	45	1.5	45	1.5	Press-fit	457
T4117B	40719	200	10	85	15	45	1.5	45	1.5	Stud	457
T4117D	40720	400	10	85	15	45	1.5	45	1.5	"	457
T2806B	40721	200	8	80	15	45	1.5	45	1.5	Plastic	364
T2806D	40722	400	8	80	15	45	1.5	45	1.5	"	364
T2606DF	40723	450	6	75	–	45	1.5	45	1.5	Mod. TO-5	375
T2616DF	40724	450	6	75	–	45	1.5	45	1.5	Mod. TO-5 on Heat Radiator	375
T2606B	40725	200	6	75	15	45	1.5	45	1.5	Mod. TO-5	352
T2606D	40726	400	6	75	15	45	1.5	45	1.5	"	352
T2706B	40727	200	6	75	15	45	1.5	45	1.5	TO-66	351
T2706D	40728	400	6	75	15	45	1.5	45	1.5	TO-66	351
T2716B	40729	200	6	75	15	45	1.5	45	1.5	TO-66 with Heat Radiator	351
T2716D	40730	400	6	75	15	45	1.5	45	1.5	"	351

▲ A triac driven directly from the output terminal of the CA3058, CA3059, and CA3079 should be characterized for operation in the I^+ or III^+ triggering modes, i.e., with positive gate current (current flows into the gate for both polarities of the applied ac voltage).

* Except for gate characteristics, data in these bulletins also apply to the types listed in this chart.

RCA
Solid State Division

Thyristors

T2500 Series

MT2
G
MT1
MT2

JEDEC TO-220AB

H-1535

6-A Silicon Triacs

Three-Lead Plastic Types for Power-Control and Power-Switching Applications

Features:

- 60-A Peak Surge Full-Cycle Current Ratings
- Shorted-Emitter, Center-Gate Design
- Package Design Facilitates Mounting on a Printed-Circuit Board
- Low Switching Losses
- Low Thermal Resistance

Voltage / Package	200 V Type	400 V Type
TO-220AB	T2500B (41014)	T2500D (41015)

Numbers in parentheses are former RCA type numbers.

Types T2500B and T2500D* are gate-controlled full-wave silicon triacs utilizing a plastic case with three leads to facilitate mounting on printed-circuit boards. They are intended for the control of ac loads in such applications as motor controls, heating controls, relay replacement, solenoid drivers, static switching, and power-switching systems.

These devices are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages. They have an on-state current rating of 6 amperes at a T_C of 80°C and repetitive off-state voltage ratings of 200 volts and 400 volts, respectively.

The unique plastic package design provides not only ease of mounting but also low terminal impedance, which allows operation at high case temperatures and permits reduced heat-sink size.

*Formerly RCA Dev. Nos. TA8504 and TA8505.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		T2500B	T2500D	
REPETITIVE PEAK OFF-STATE VOLTAGE:●				
Gate open, T_J = −65 to 100°C	V_{DROM}	200	400	V
RMS ON-STATE CURRENT (Conduction angle = 360°):				
Case temperature	$I_{T(RMS)}$			
T_C = 80°C		6		A
For other conditions		See *Fig. 3*		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:				
For one cycle of applied principal voltage, T_C = 80°C	I_{TSM}			
60 Hz (sinusoidal)		60		A
50 Hz (sinusoidal)		50		A
For more than one cycle of applied principal voltage		See *Fig. 4*		
RATE OF CHANGE OF ON-STATE CURRENT:				
$V_{DM} = V_{DROM}$, I_{GT} = 200 mA, tr = 0.1 µs (See Fig. 16)	di/dt	70		A/µs
FUSING CURRENT (for Triac Protection):				
T_C = −65 to 100°C, t = 1.25 to 10 ms	I^2t	18		A^2s
PEAK GATE-TRIGGER CURRENT:■				
For 10 µs max; see *Fig. 10*	I_{GTM}	4		A
GATE POWER DISSIPATION:				
Peak (For 1 µs max., $I_{GTM} \leq 4$ A; see *Fig. 10)*	P_{GM}	16		W
AVERAGE	$P_{G(AV)}$	0.2		W
TEMPERATURE RANGE:▲				
Storage	T_{stg}	−65 to 150		°C
Operating (Case)	T_C	−65 to 100		°C
TERMINAL TEMPERATURE (During soldering):				
For 10 s max. (terminals and case)	T_T	225		°C

● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.
▲ For temperature measurement reference point, see *Dimensional Outline*.

ELECTRICAL CHARACTERISTICS at Maximum Ratings unless otherwise specified, and at indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS						UNITS
		T2500B			T2500D			
		MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	
Peak Off-State Current:* Gate Open, V_{DROM} = Max. rated value At T_J = 100°C	I_{DROM}	–	0.1	2	–	0.1	2	mA
Maximum On-State Voltage:* For i_T = 30 A (peak) and T_C = 25°C	V_{TM}	–	1.7	2	–	1.7	2	V
DC Holding Current:* Gate Open Initial principal current = 150 mA (dc) At T_C = 25°C	I_{HO}	–	15	30	–	15	30	mA
For other case temperatures		← See Fig. 8. →						
Critical Rate of Rise of Commutation Voltage:*◆ For v_D = V_{DROM}, $I_{T(RMS)}$ = 6 A, Commutating di/dt = 3.2 A/ms, and gate unenergized At T_C = 80°C	dv/dt	4	10	–	4	10	–	V/μs
Critical Rate of Rise of Off-State Voltage:* For v_D = V_{DROM}, exponential voltage rise, and gate open At T_C = 100°C	dv/dt	100	300	–	75	250	–	V/μs
For other case temperatures		← See Fig.9 →						
DC Gate-Trigger Current:*† For v_D = 12 V (dc), R_L = 12 Ω T_C = 25°C, and specified triggering mode:	I_{GT}							mA
I⁺ Mode (V_{MT2} positive, V_G positive)		–	10	25	–	10	25	
III⁻ Mode (V_{MT2} negative, V_G negative)		–	15	25	–	15	25	
I⁻ Mode (V_{MT2} positive, V_G negative)		–	20	60	–	20	60	
III⁺ Mode (V_{MT2} negative, V_G positive)		–	30	60	–	30	60	
For other case temperatures		← See Figs. 12 and 13 →						
DC Gate-Trigger Voltage:*† For v_D = 12 V (dc) and R_L = 12 Ω At T_C = 25°C	V_{GT}	–	1.25	2.5	–	1.25	2.5	V
For other case temperatures		← See Fig. 14. →						
For v_D = V_{DROM} and R_L = 125 Ω At T_C = 100°C		0.2	–	–	0.2	–	–	
Gate-Controlled Turn-On Time (Delay Time + Rise Time): For v_D = V_{DROM}, I_{GT} = 160 mA, rise time = 0.1 μs, and i_T = 10 A (peak) At T_C = 25°C (See Fig.15.)	t_{gt}	–	1.6	2.5	–	1.6	2.5	μs
Thermal Resistance: Junction-to-Case	$R_{\theta JC}$	–	–	2.7	–	–	2.7	°C/W
Junction-to-Ambient	$R_{\theta JA}$	–	–	60	–	–	60	°C/W

*For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

†For either polarity of gate voltage (V_G) with reference to main terminal 1.

◆Variants of these devices having dv/dt characteristics selected specifically for inductive loads are available on special order; for additional information, contact your RCA Representative or your RCA Distributor.

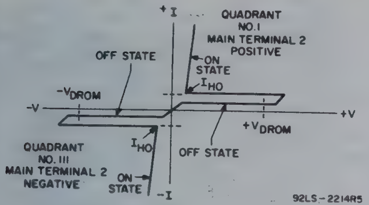


Fig. 1—Principal voltage-current characteristic.

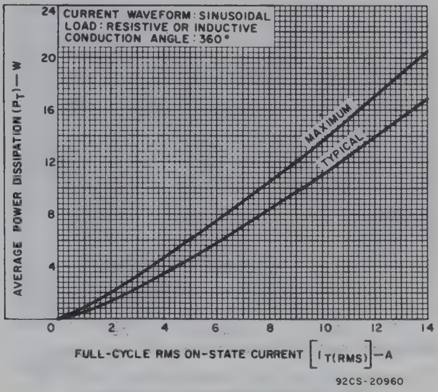


Fig. 2—Power dissipation vs. on-state current.

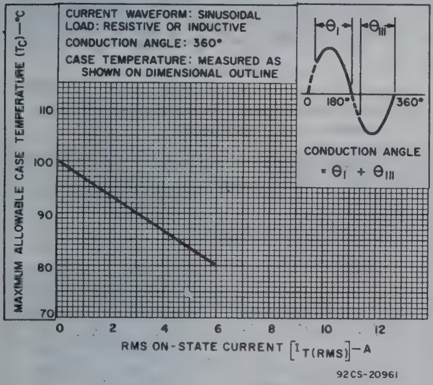


Fig. 3—Allowable case temperature vs. on-state current.

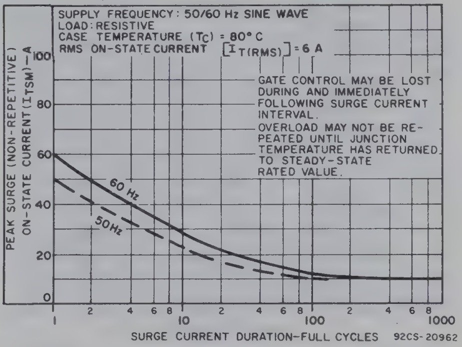


Fig. 4—Peak surge on-state current vs. surge current duration.

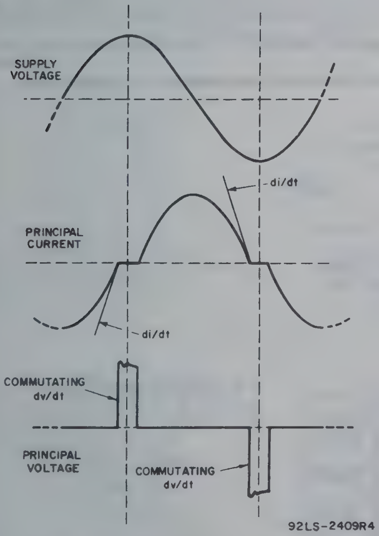

SUPPLY
VOLTAGE
-di/dt
PRINCIPAL
CURRENT
-di/dt
COMMUTATING
dv/dt
PRINCIPAL
VOLTAGE
COMMUTATING
dv/dt
92LS-2409R4

Fig. 5—Oscilloscope display of commutating dv/dt.

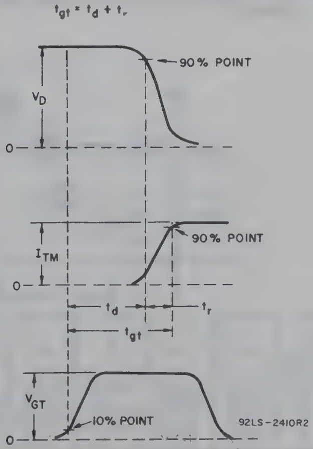

$t_{gt} = t_d + t_r$
90% POINT
V_D
0
90% POINT
I_{TM}
0
t_d
t_r
t_{gt}
V_{GT}
10% POINT
0
92LS-2410R2

Fig. 6—Oscilloscope display for measurement of gate-controlled turn-on time (t_{gt}).

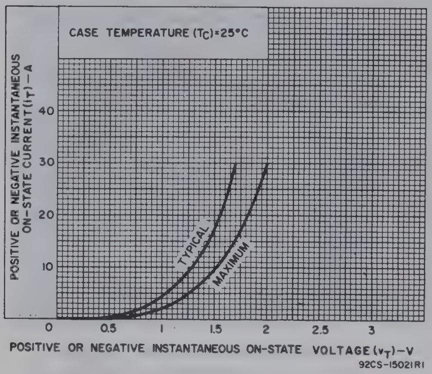


Fig. 7—On-state current vs. on-state voltage.

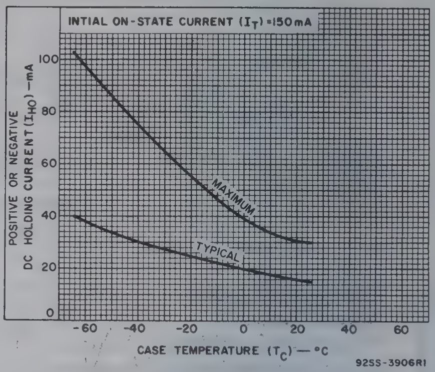


Fig. 8—DC holding current for either direction of on-state current vs. case temperature.

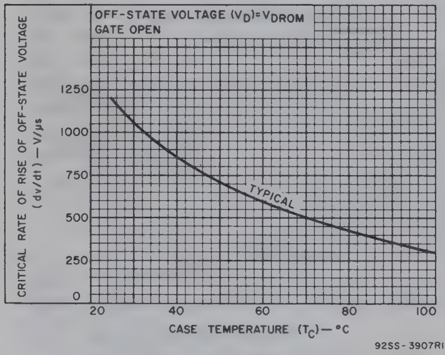


Fig. 9—Critical rate of rise of off-state voltage vs. case temperature.

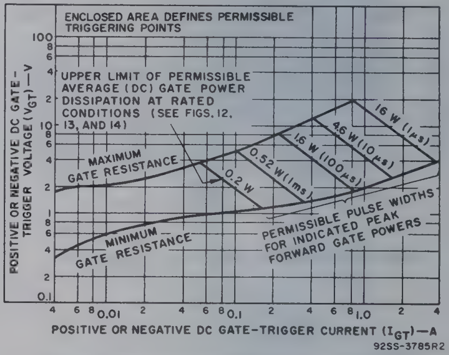
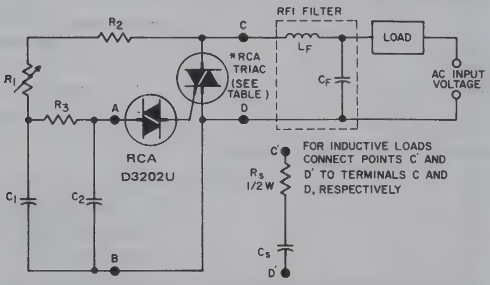


Fig. 10—Gate pulse characteristics for all triggering modes.


R2
C
RFI FILTER
L_F
LOAD
R1
*RCA TRIAC (SEE TABLE)
C_F
AC INPUT VOLTAGE
R3
A
D
RCA D3202U
C'
R_S 1/2 W
FOR INDUCTIVE LOADS CONNECT POINTS C' AND D' TO TERMINALS C AND D, RESPECTIVELY
C1
C2
B
C_S
D'

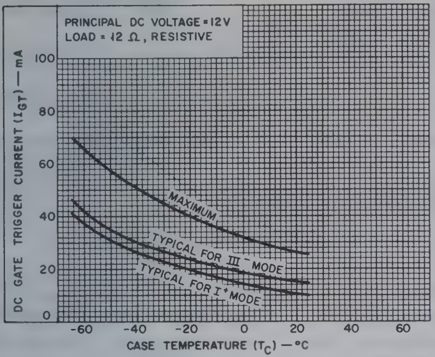
	120 V	240 V
C_s	0.047 μF/200 V	0.047 μF/400 V
R_s	1.8 KΩ	1.8 KΩ

92CS-20963R1

AC INPUT VOLTAGE	C_1	C_2	R_1	R_2	R_3	RFI FILTER		RCA TYPES
						L_F* (typ.)	C_F* (typ.)	
120 V 60 Hz	0.1 μF 200 V	0.1 μF 100 V	100 KΩ ½ W	2.2 KΩ ½ W	15 KΩ ½ W	100 μH	0.1 μF 200V	T2500B
240 V 50 Hz	0.1 μF 400 V	0.1 μF 100 V	250 KΩ 1 W	3.3 KΩ ½ W	15 KΩ ½ W	200 μH	0.1 μF 400 V	T2500D
240 V 60 Hz	0.1 μF 400 V	0.1 μF 100 V	200 KΩ 1 W	3.3 KΩ ½ W	15 KΩ ½ W	200 μH	0.1 μF 400 V	T2500D

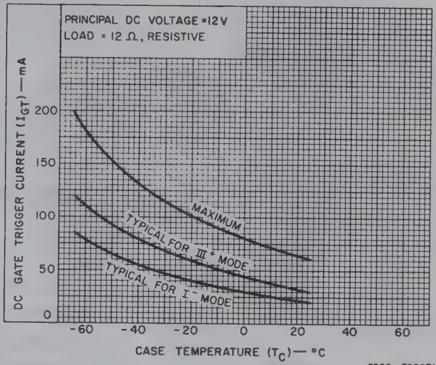
*Typical values for lamp-dimming circuits.

Fig. 11 — Typical phase-control circuit for lamp dimming, heat controls, and universal motor speed controls.



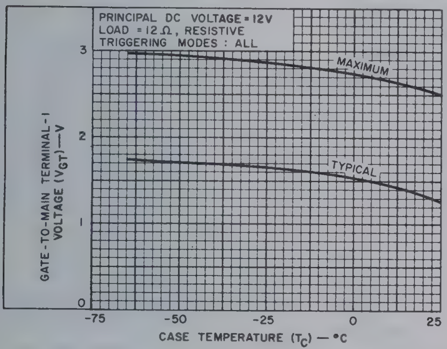
92SS-3908R1

Fig. 12—DC gate-trigger current (for I^+ and III^- triggering modes) vs. case temperature.



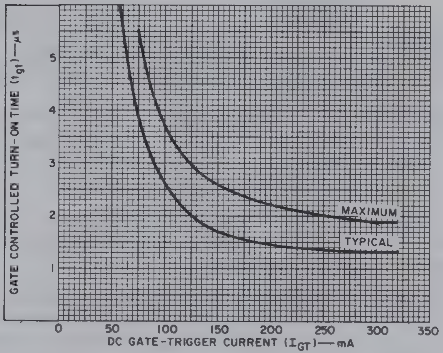
92SS-3909R1

Fig. 13—DC gate-trigger current (for I^- and III^+ triggering modes) vs. temperature.



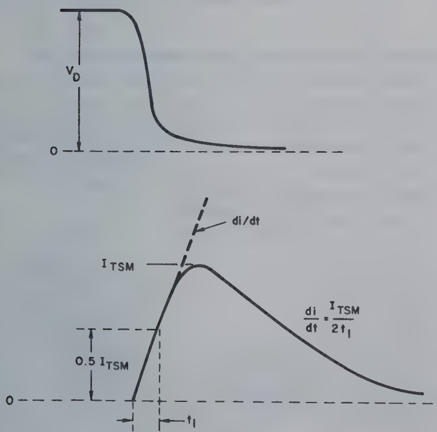
92SS-3916R1

Fig. 14—DC gate-trigger voltage vs. case temperature.



92CS-17062

Fig. 15—Typical turn-on time vs. gate-trigger current.



92CS-17063

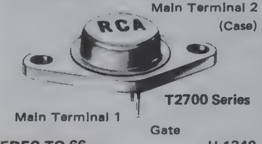
Fig. 16—Rate-of-change of on-state current with time (defining di/dt).

TERMINAL CONNECTIONS

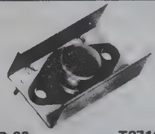
Lead No. 1—Main Terminal 1
Lead No. 2—Main Terminal 2
Lead No. 3—Gate
Mounting Flange—Main Terminal 2

RCA
Solid State Division

Thyristors
T2700 T2710 Series



JEDEC TO-66 H-1340



JEDEC TO-66 T2710 Series
With Integral Heat Radiator H-1470A

6-Ampere Silicon Triacs

For Power-Control and Power-Switching Applications

Features:

- **Shorted-emitter construction . . . contains an internally diffused resistor between gate and Main Terminal 1**
- **Center gate construction . . . provides rapid uniform gate-current spreading f faster turn-on with substantially reduc heating effects**

Package \ Voltage	200 V Types	400 V Types
TO-66	T2700B (40429)	T2700D (40430)
TO-66 with Heat Radiator	T2710B (40502)	T2710D (40503)

Numbers in parentheses are former RCA type numbers.

RCA T2700- and T2710-series devices are gate-controlled full-wave silicon triacs. They are intended for the control of ac loads in applications such as heating controls, motor controls, light dimmers, and power switching systems.

These triacs are designed to switch from an off-state to an on-state condition for either polarity of applied voltage with positive or negative triggering voltages to the gate.

T2700B and T2700D are hermetically sealed types having an on-state current rating of 6 amperes at a case temperature of +75°C and repetitive off-state voltage ratings of 200 volts and 400 volts, respectively.

These devices are also available with integral heat radiators, as T2710B and T2710D, respectively.

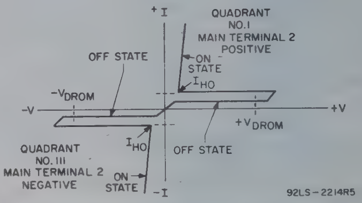


Fig. 1 — Principal voltage-current characteristic.

Maximum Ratings, *Absolute-Maximum Values:*

For Operation with Sinusoidal Supply Voltage at Frequencies of 50/60 Hz, and with Resistive or Inductive Load

	T2700B T2710B	T2700D T2710D	
REPETITIVE PEAK OFF-STATE VOLTAGE♦, V_{DROM}:			
Gate Open, For T_J = −65 to +100 °C	200	400	V
RMS ON-STATE CURRENT, $I_{t(rms)}$:			
For case temperature (T_C) of +75 °C and a conduction angle of 360°	6 (40429)	6 (40430)	A
For ambient temperatures (T_A) up to +100 °C and a conduction angle of 360°	See Fig. 16.		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT, I_{TSM}:			
For one cycle of applied principal voltage, $T_C = 75^\circ C$			
60 Hz (sinusoidal)	100	100	A
50 Hz (sinusoidal)	85	85	A
For more than one full cycle of applied voltage	See Fig. 4.		
RATE OF CHANGE OF ON-STATE CURRENT:			
$V_{DM} = V_{DROM}$, I_{GT} = 200 mA, tr = 0.1 μs di/dt	100		A/μs
FUSING CURRENT (for triac protection, I^2t:			
T_J = −65 to 100°C, t = 1.25 to 10 ms	50	50	A^2s
PEAK GATE-TRIGGER CURRENT■, I_{GTM}:			
For 1 μs max.	4	4	A
GATE POWER DISSIPATION:■			
PEAK, P_{GM} For 1 μs max. and $I_{GTM} \leq 4$ A (peak)	16	16	W
AVERAGE, $P_{G(AV)}$	0.2	0.2	W
TEMPERATURE RANGE♦:			
Storage	−65 to +150		°C
Operating (case)	−65 to +100		°C

♦For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

■For either polarity of gate voltage (V_{GT}) with reference to main terminal 1.

♦For information on the reference point of temperature measurement, see *Dimensional Outline*.

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified
(For Definitions of Terms and Symbols, See Page 6)

CHARACTERISTIC	SYMBOL	LIMITS												UNITS
		T2700B			T2710B			T2700D			T2710D			
		Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
Peak Off-State Current:* Gate Open At T_J = + 100 °C and V_{DROM} = Max. rated value	I_{DROM}	–	0.1	4	–	0.1	1.2	–	0.2	4	–	0.2	1.2	mA
Maximum On-State Voltage:* For i_T = 30A (peak) and T_C = +25 °C	v_{TM}	–	1.8	2.25	–	1.8	2.25	–	1.8	2.25	–	1.8	2.25	V
DC Holding Current:* Gate Open Initial principal current = 150 mA (DC) At T_C = +25 °C	I_{HO}	–	15	30	–	15	30	–	15	30	–	15	30	mA
For other case temperatures		See Fig. 8.												
Critical Rate of Rise of Commutation Voltage:*♦ For V_D = V_{DROM}, $I_{t(rms)}$ = 6 A, commutating di/dt = 3.2 A/ms, and gate unenergized At T_C = +75 °C	dv/dt	3	10	–	–	–	–	3	10	–	–	–	–	V/µs
$I_{t(rms)}$ and T_A specified by curve A of Fig. 16		–	–	–	3	10	–	–	–	–	3	10	–	
$I_{t(rms)}$ and T_A specified by curve B of Fig. 16		–	–	–	4	12	–	–	–	–	4	12	–	
Critical Rate of Rise of Off-State Voltage:* For V_D = V_{DROM}, exponential voltage rise, and gate open At T_C = + 100 °C	dv/dt	30	150	–	30	150	–	20	100	–	20	100	–	V/µs
DC Gate-Trigger Current:*† For V_D = 12 volts (DC), R_L = 12 Ω T_C = +25 °C, and specified triggering mode: I+ Mode: positive V_{MT2}, positive V_{GT}	I_{GT}	–	15	25	–	15	25	–	15	25	–	15	25	mA
III– Mode: negative V_{MT2}, negative V_{GT}		–	15	25	–	15	25	–	15	25	–	15	25	
I– Mode: positive V_{MT2}, negative V_{GT}		–	25	40	–	25	40	–	25	40	–	25	40	
III+ Mode: negative V_{MT2}, positive V_{GT}		–	25	40	–	25	40	–	25	40	–	25	40	
For other case temperatures		See Fig. 12 & 13.												
DC Gate-Trigger Voltage:*† For V_D = 12 volts (DC) and R_L = 12 Ω At T_C = +25 °C	V_{GT}	–	1	2.2	–	1	2.2	–	1	2.2	–	1	2.2	V
For other case temperatures		See Fig. 14.												
For V_D = V_{DROM} and R_L = 125 Ω At T_C = + 100 °C		0.2	–	–	0.2	–	–	0.2	–	–	0.2	–	–	
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For V_D = V_{DROM} and I_{GT} = 80 mA, 0.1 µs rise time, and i_T = 10 A (peak) At T_C = +25 °C	t_{gt}	–	2.2	–	–	2.2	–	–	2.2	–	–	2.2	–	µs
Thermal Resistance: Junction-to-Case (Steady-State)	θ_{J-C}	–	–	4	–	–	–	–	–	4	–	–	–	°C/W
Junction-to-Case (Transient)		See Fig. 15.												
Junction-to-Ambient	θ_{J-A}	–	–	–	See Fig. 16.			–	–	–	See Fig. 16.			

*For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

†For either polarity of gate voltage (V_{GT}) with reference to main terminal 1.

♦Variants of these devices having dv/dt characteristics selected specifically for inductive loads are available on special order; for additional information, contact your RCA Representative or your RCA Distributor.

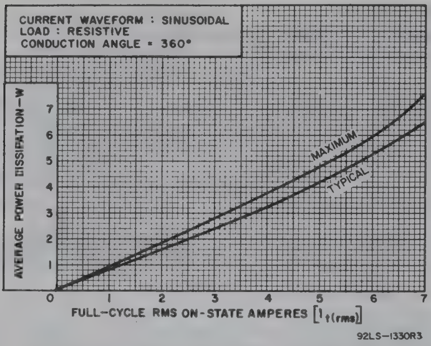


Fig. 2 — Power dissipation vs. on-state current.

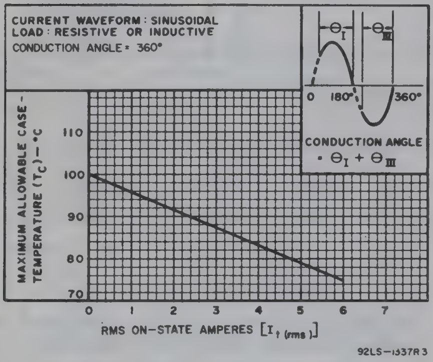


Fig. 3 — Allowable case temperature vs. on-state current.

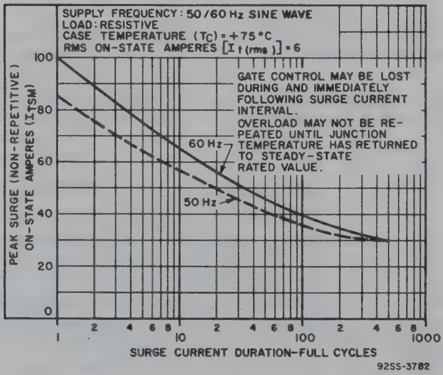


Fig. 4 — Peak surge on-state current vs. surge current duration.

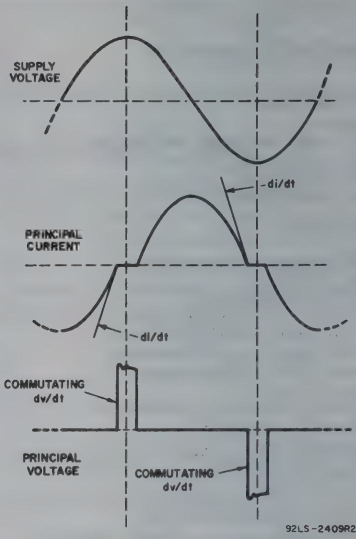

SUPPLY VOLTAGE
-di/dt
PRINCIPAL CURRENT
-di/dt
COMMUTATING dv/dt
PRINCIPAL VOLTAGE
COMMUTATING dv/dt
92LS-2409R2

Fig. 5 — Oscilloscope display of commutating dv/dt.

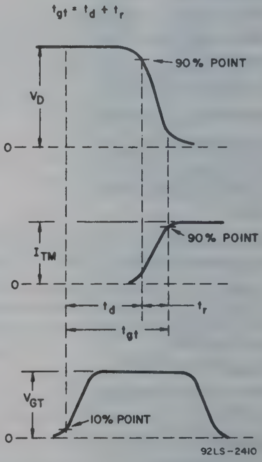

$t_{gt} = t_d + t_r$
90% POINT
V_D
0
I_{TM}
90% POINT
0
t_d
t_r
t_{gt}
V_{GT}
10% POINT
0
92LS-2410

Fig. 6 — Oscilloscope display for measurement of gate-controlled turn-on time (t_{gt}).

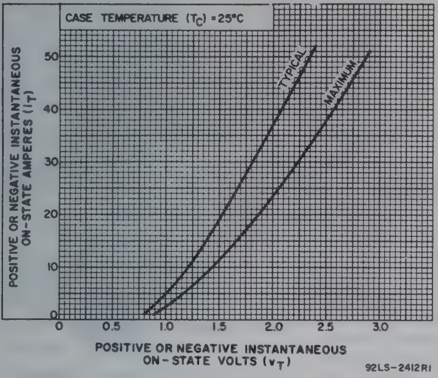


Fig. 7 — On-state current vs. on-state voltage.

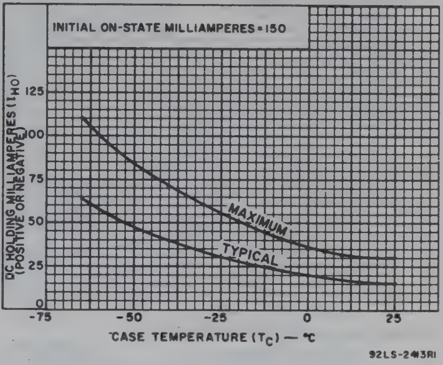


Fig. 8 — DC holding current for either direction of on-state current vs. case temperature.

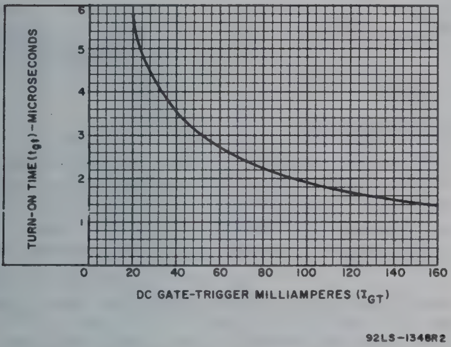


Fig. 9 — Typical turn-on time vs. gate-trigger current.

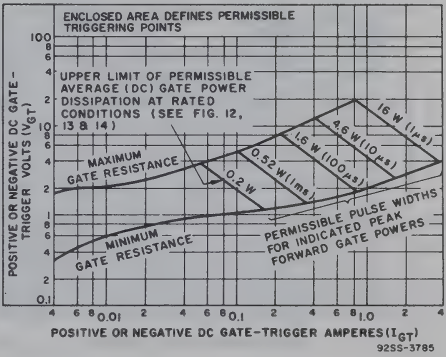


Fig. 10 — Gate pulse characteristics for all triggering modes.

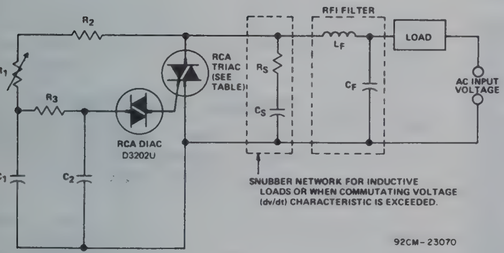

R2
R1
R3
RCA DIAC D3202U
RCA TRIAC (SEE TABLE)
RS
CS
RFI FILTER
LF
CF
LOAD
AC INPUT VOLTAGE
C1
C2
SNUBBER NETWORK FOR INDUCTIVE LOADS OR WHEN COMMUTATING VOLTAGE (dv/dt) CHARACTERISTIC IS EXCEEDED.
92CM-23070

Fig. 11 — Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.

AC INPUT VOLTAGE		120 V 60 Hz	240 V 60 Hz	240 V 50 Hz
C_1		0.1 μF 200 V	0.05 μF 400 V	0.05 μF 400 V
C_2		0.1 μF 100 V	0.1 μF 100 V	0.1 μF 100 V
R_1		100 KΩ 1/2 W	200 KΩ 1 W	200 KΩ 1 W
R_2		1 KΩ 1/2 W	7.5 KΩ 2 W	7.5 KΩ 2 W
R_3		15 KΩ 1/2 W	7.5 KΩ 2 W	7.5 KΩ 2 W
SNUBBER NETWORK	C_S	0.1 μF 200 V	0.1 μF 400 V	0.1 μF 400 V
	R_S	47 Ω 1/2 W	47 Ω 1/2 W	47 Ω 1/2 W
RFI FILTER	C_F*	0.1 μF 200 V	0.1 μF 400 V	0.1 μF 400 V
	L_F*	100 μH	100 μH	100 μH
RCA TRIACS		T2700B T2710B	T2700D T2710D	T2700D T2710D

*Typical values for lamp dimming circuits.

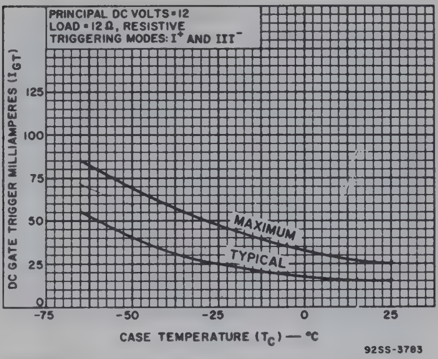


Fig. 12 — DC gate-trigger current (for I^+ and III^- triggering modes) vs. case temperature.

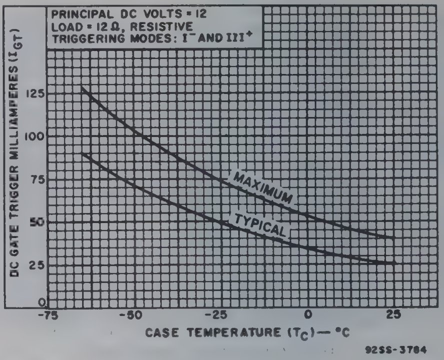


Fig. 13 — DC gate-trigger current (for I^- and III^+ triggering modes) vs. case temperature.

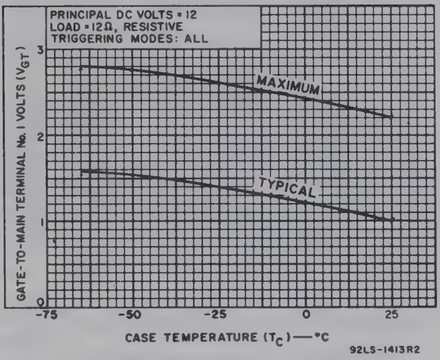


Fig. 14 — DC gate-trigger voltage vs. case temperature.

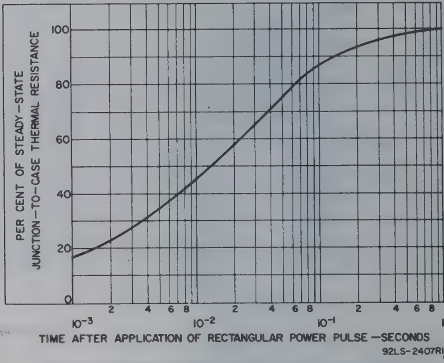


Fig. 15 — Transient thermal resistance (junction-to-case vs. time).

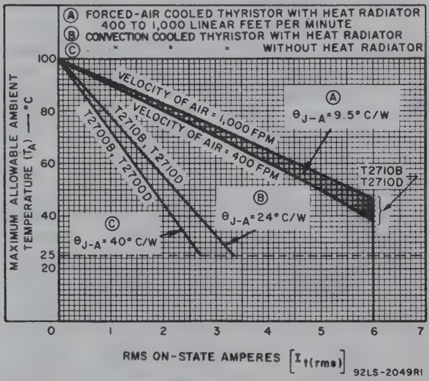


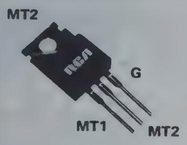
Fig. 16 — Maximum allowable ambient temperature vs. on-state current.

TERMINAL CONNECTIONS

Pin No. 1 -- Gate
Pin No. 2 — Main Terminal 1
Case/Heat Radiator — Main Terminal 2

RCA
Solid State
Division

Thyristors
T2800
T2802
Series



JEDEC TO-220AB H-1535

8-A Silicon Triacs

Three-Lead Plastic Types for
Power-Control and Power-Switching Applications

Features:

- 100-A Peak Surge Full-Cycle Current Ratings
- Shorted-Emitter Center-Gate Design
- Low Switching Losses
- Low Thermal Resistance
- Package Design Facilitates Mounting on a Printed-Circuit Board

Voltage / Package	200 V Types	300 V Types	400 V Types	500 V Types	600 V Types
TO-220AB	T2800B (40668)	T2800C	T2800D (40669)	T2800E	T2800M (40670)
	T2802B	T2802C	T2802D	T2802E	T2802M

Numbers in parentheses are former RCA type numbers.

The RCA-T2800 and T2802 series triacs are gate-controlled full-wave silicon switches utilizing a plastic case with three leads to facilitate mounting on printed-circuit boards. They are intended for the control of ac loads in such applications as motor controls, light dimmers, heating controls, and power-switching systems.

These devices are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages. They have an on-state current rating of 8 amperes at a T_C of 80°C and repetitive off-state voltage ratings of 200, 300, 400, 500 and 600 volts.

The T2802 series triacs are characterized for I^+, III^- gate triggering modes only and should suit a wide range of applications that employ diac or anode on/off triggering.

The plastic package design provides not only ease of mounting but also low thermal impedance, which allows operation at high case temperatures and permits reduced heat-sink size.

MAXIMUM RATINGS, ***Absolute-Maximum Values:***
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		T2800B T2802B	T2800C T2802C	T2800D T2802D	T2800E T2802E	T2800M T2802M	
REPETITIVE PEAK OFF-STATE VOLTAGE:•							
Gate open, T_J = −65 to 100°C	V_{DROM}	200	300	400	500	600	V
RMS ON-STATE CURRENT (Conduction angle = 360°):	$I_{T(RMS)}$						
Case temperature							
T_C = 80°C		8					A
For other conditions		See Fig. 3					
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}						
For one cycle of applied principal voltage							
60 Hz (sinusoidal), T_C = 80°C		100					A
50 Hz (sinusoidal), T_C = 80°C		85					A
For more than one cyle of applied principal voltage		See Fig. 4					
RATE OF CHANGE OF ON-STATE CURRENT:							
$v_D = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.1 μs (See Fig. 13)	di/dt	70					A/μs
FUSING CURRENT (for triac protection):							
T_J = −65 to 100°C, t = 1.25 to 10 ms	I^2t	50					A^2s
PEAK GATE-TRIGGER CURRENT:■							
For 1 μs max., See Fig. 5	I_{GTM}	4					A

• For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

■ For either polarity of gate voltage (V_G) with reference to main terminal 1.

▲ For temperature measurement reference point, see Dimensional Outline.

MAXIMUM RATINGS (Cont'd)

GATE POWER DISSIPATION:		
Peak (For 1 µs max., I_{GTM} ≤ 4 A, See Fig. 5	P_{GM}	16
AVERAGE	$P_{G(AV)}$	0.35
TEMPERATURE RANGE:▲		
Storage	T_{stg}	–65 to 150
Operating (Case)	T_C	–65 to 100
TERMINAL TEMPERATURE (During soldering):		
For 10 s max. (terminals and case)	T_T	225

See preceding page for applicable footnotes.

ELECTRICAL CHARACTERISTICS, *At Maximum Ratings Unless Otherwise Specified, and at Indicated Temperature*

CHARACTERISTIC	SYMBOL	LIMITS For All Types Except as Specified			UNIT
		MIN.	TYP.	MAX.	
Peak Off-State Current:● Gate open, T_J = 100°C, V_{DROM} = Max. rated value	I_{DROM}	–	0.1	2	m
Maximum On-State Voltage:● For i_T = 30 A (peak), T_C = 25°C (See Fig. 6)	v_{TM}	–	1.7	2	V
DC Holding Current:● Gate open, Initial principal current = 150 mA (dc) v_D = 12 V, T_C = 25°C, T2800 series	I_{HO}	–	15	30	m
T2802 series		–	20	60	
For other case temperatures		See Fig. 7			
Critical Rate-of-Rise of Commutation Voltage:● ▲ For v_D = V_{DROM}, $I_{T(RMS)}$ = 8 A, commutating di/dt = 4.3A/ms, gate unenergized, T_C = 80°C (See Fig. 14)	dv/dt	4	10	–	V/
Critical Rate-of-Rise of Off-State Voltage:● For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 100°C: T2800B, T2802B	dv/dt	100	300	–	V/
T2800C, T2802C		85	275	–	
T2800D, T2802D		75	250	–	
T2800E, T2802E		65	225	–	
T2800M, T2802M		60	200	–	
DC Gate-Trigger Current:● ■ For v_D = 12 V (dc), R_L = 12 Ω, T_C = 25°C — Mode I^+, V_{MT2} positive, V_G positive . . T2800 series	I_{GT}	–	10	25	m
. . T2802 series		–	25	50	
Mode III^-, V_{MT2} negative, V_G negative . T2800 series		–	15	25	
. . T2802 series		–	25	50	
Mode I^-, V_{MT2} positive, V_G negative . T2800 series only		–	20	60	
Mode III^+, V_{MT2} negative, V_G positive . . T2800 series only		–	30	60	
For other case temperatures		See Figs. 9 & 10			
DC Gate-Trigger Voltage:● ■ For v_D = 12 V (dc), R_L = 12 Ω, T_C = 25°C	V_{GT}	–	1.25	2.5	V
For other case temperatures		See Fig. 11			
For v_D = V_{DROM}, R_L = 125 Ω, T_C = 100°C		0.2	–	–	
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For v_D = V_{DROM}, I_{GT} = 80 mA, t_r = 0.1 µs, i_T = 10 A (peak), T_C = 25°C (See Figs. 12 & 15)	t_{gt}	–	1.6	2.5	µ

See following page for applicable footnotes.

CTRICAL CHARACTERISTICS (Cont'd)

CHARACTERISTIC	SYMBOL	LIMITS For All Types Except as Specified			UNITS
		MIN.	TYP.	MAX.	
ermal Resistance:					
Junction-to-Case	$R_{\theta JC}$	–	–	2.2	°C/W
Junction-to-Ambient	$R_{\theta JA}$	–	–	60	

or either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

or either polarity of gate voltage (V_G) with reference to main terminal 1.

ariants of these devices having dv/dt characteristics selected specifically for inductive loads are available on special order; r additional information, contact your RCA Representative or your RCA Distributor.

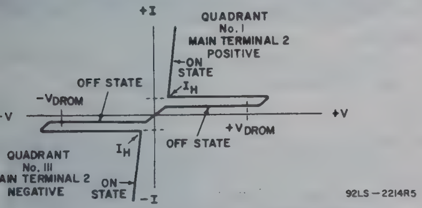
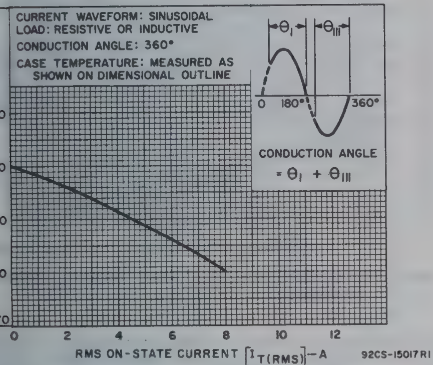

+I
QUADRANT
No. I
MAIN TERMINAL 2
POSITIVE
ON
STATE
I_H
OFF STATE
$-V_{DROM}$
-V
+V
$+V_{DROM}$
OFF STATE
I_H
QUADRANT
No. III
AIN TERMINAL 2
NEGATIVE
ON
STATE
-I
92LS—2214R5

Fig. 1 — Principal voltage-current characteristic.



3 — Maximum allowable case temperature vs. on-state current.

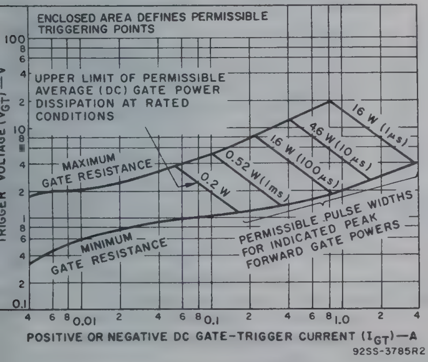


Fig. 5 — Gate pulse characteristics for all triggering modes.

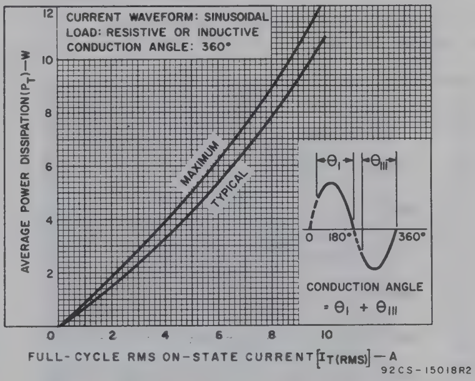


Fig. 2 — Power dissipation vs. on-state current.

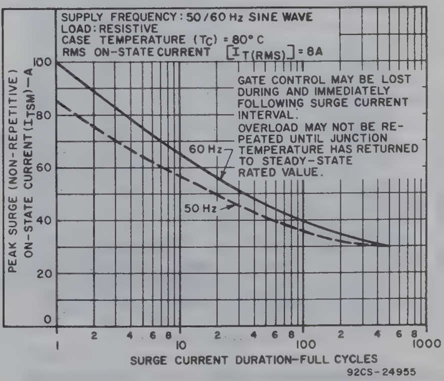


Fig. 4 — Peak surge on-state current vs. surge current duration.

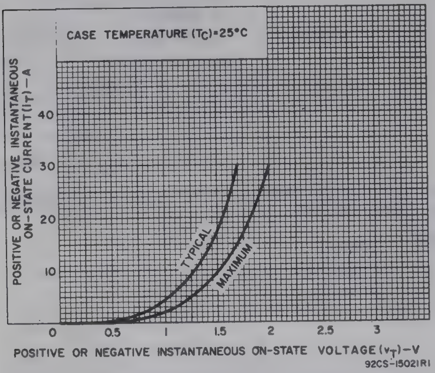


Fig. 6 – On-state current vs. on-state voltage.

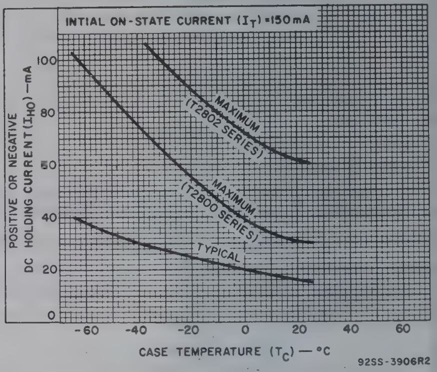


Fig. 7 – DC holding current vs. case temperature.

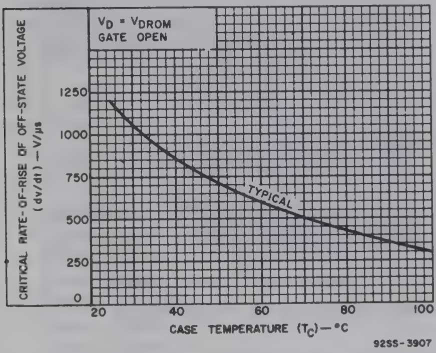


Fig. 8 – Typical critical rate-of-rise of off-state voltage vs. case temperature.

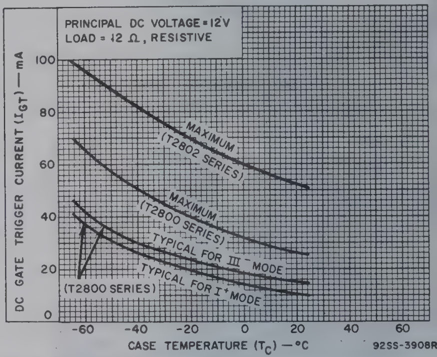


Fig. 9 – DC gate-trigger current (for I^+ and III^- triggering modes) vs. case temperature.

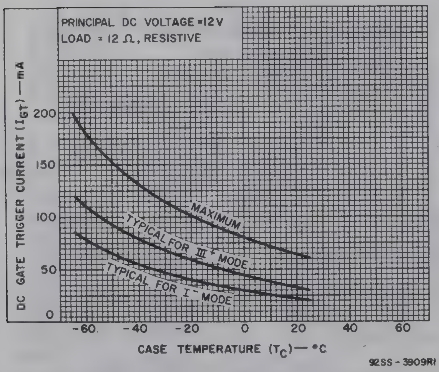


Fig. 10 – DC gate-trigger current (for I^- and III^+ triggering modes) vs. case temperature for T2800 series only.

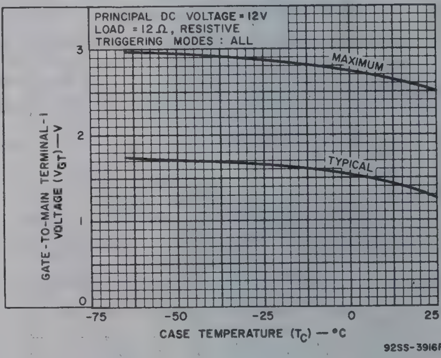


Fig. 11 – DC gate-trigger voltage vs. case temperature.

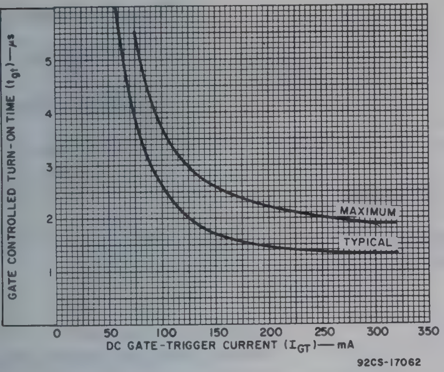


Fig. 12 – Turn-on time vs. gate-trigger current.

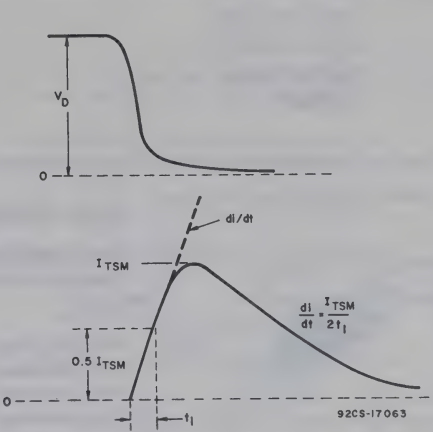

V_D
0
di/dt
I_{TSM}
$\frac{di}{dt} = \frac{I_{TSM}}{2t_1}$
$0.5\ I_{TSM}$
0
t_1
92CS-17063

Fig. 13 – Rate-of-change of on-state current with time (defining di/dt).

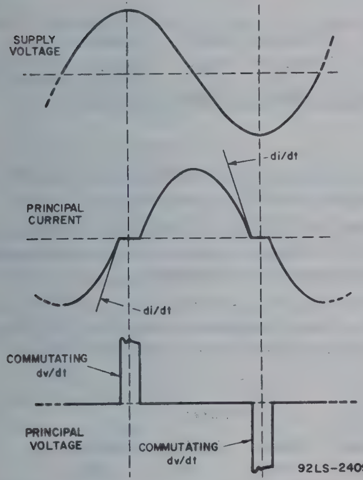

SUPPLY VOLTAGE
-di/dt
PRINCIPAL CURRENT
di/dt
COMMUTATING dv/dt
PRINCIPAL VOLTAGE
COMMUTATING dv/dt
92LS-2409R4

Fig. 14 – Relationship between supply voltage and principal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

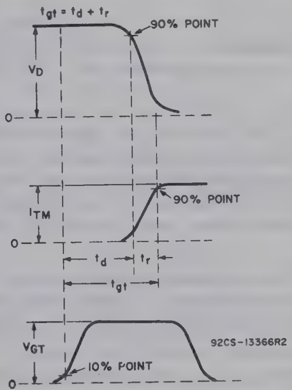

$t_{gt} = t_d + t_r$
90% POINT
V_D
0
I_{TM}
90% POINT
0
t_d
t_r
t_{gt}
V_{GT}
92CS-13366R2
10% POINT
0

Fig. 15 – Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).

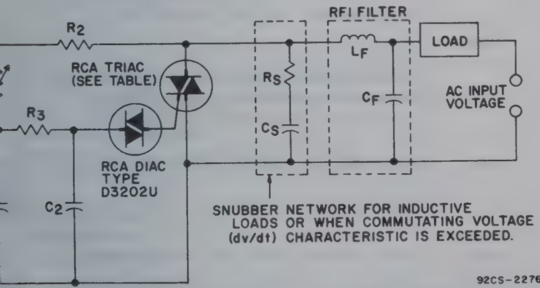

R_2
RCA TRIAC (SEE TABLE)
R_3
RCA DIAC TYPE D3202U
C_2
R_S
C_S
RFI FILTER
L_F
C_F
LOAD
AC INPUT VOLTAGE
SNUBBER NETWORK FOR INDUCTIVE LOADS OR WHEN COMMUTATING VOLTAGE (dv/dt) CHARACTERISTIC IS EXCEEDED.
92CS-22765

Fig. 16 – Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.

AC INPUT VOLTAGE		120 V 60 Hz	240 V 60 Hz	240 V 50 Hz
C_1		0.1 µF 200 V	0.1 µF 400 V	0.1 µF 400 V
C_2		0.1 µF 100 V	0.1 µF 100 V	0.1 µF 100 V
R_1		100 kΩ ½ W	200 kΩ ½ W	250 kΩ ½ W
R_2		2.2 kΩ ½ W	3.3 kΩ ½ W	3.3 kΩ ½ W
R_3		15 kΩ ½ W	15 kΩ ½ W	15 kΩ ½ W
SNUBBER NETWORK FOR 8A (RMS)● INDUCTIVE LOAD	C_S	0.068 µF 200 V	0.1 µF 400 V	0.1 µF 400 V
	R_S	1.2 kΩ ½ W	1 kΩ ½ W	1 kΩ ½ W
RFI FILTER	C_F●	0.1 µF 200 V	0.1 µF 400 V	0.1 µF 400 V
	L_F●	100 µH	200 µH	200 µH
RCA TRIACS		T2800B T2800C T2802B T2802C	T2800D T2802D	T2800D T2802D

● For other RMS Current values refer to RCA Application Note AN-4745.

●Typical values for Lamp dimming circuits.

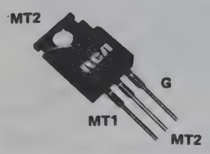
TERMINAL CONNECTIONS

Lead No. 1—Main Terminal 1
Mounting Flange, Lead No. 2—Main Terminal 2
Lead No. 3—Gate

RCA

Solid State
Division

Thyristors
T2801
Series



JEDEC TO-220AB H-1535

6-A Silicon Triacs

Three-Lead Plastic Types for
Power-Control and Power-Switching Applications

Features:

- **80-A Peak Surge Full-Cycle Current Ratings**
- **Shorted-Emitter Center-Gate Design**
- **Low Switching Losses**
- **Low Thermal Resistance**
- **Package Design Facilitates Mountin on a Printed-Circuit Board**

Package \ Voltage	200 V Type	300 V Type	400 V Type	500 V Type
TO-220AB	T2801B	T2801C	T2801D	T2801E

The RCA-T2801 series triacs are gate-controlled full-wave silicon switches utilizing a plastic case with three leads to facilitate mounting on printed-circuit boards. They are intended for the control of ac loads in such applications as motor controls, light dimmers, heating controls, and power-switching systems.

These devices are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages. They have an on-state current rating of 6 amperes at a T_C of 80°C and repetitive off-stat voltage ratings of 200, 300, 400, and 500 volts.

These devices are characterized for I^+, III^- gate-triggerin modes only and should suit a wide range of applications tha employ diac or anode on/off triggering.

The plastic package design provides not only ease of mountin but also low thermal impedance, which allows operation a high case temperatures and permits reduced heat-sink size.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		T2801B	T2801C	T2801D	T2801E	
REPETITIVE PEAK OFF-STATE VOLTAGE:●						
Gate open, T_J = −65 to 100°C	V_{DROM}	200	300	400	500	
RMS ON-STATE CURRENT (Conduction angle = 360°):	$I_{T(RMS)}$					
Case temperature						
T_C = 80°C		6				
For other conditions		See Fig. 3				
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}					
For one cycle of applied principal voltage						
60 Hz (sinusoidal), T_C = 80°C		80				
50 Hz (sinusoidal), T_C = 80°C		65				
For more than one cycle of applied principal voltage		See Fig. 4				
RATE OF CHANGE OF ON-STATE CURRENT:						
$V_D = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.1 µs (See Fig. 11)	di/dt	70				A/
FUSING CURRENT (for triac protection):						
T_J = −65 to 100°C, t = 1.25 to 10 ms	I^2t	35				A
PEAK GATE-TRIGGER CURRENT:■						
For 1 µs max., See Fig. 5	I_{GTM}	4				

● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

■ For either polarity of gate voltage (V_G) with reference to main terminal 1.

▲ For temperature measurement reference point, see *Dimensional Outline*.

AXIMUM RATINGS (Cont'd)

ATE POWER DISSIPATION:

Peak (For 1 µs max., $I_{GTM} \leqslant$ 4 A, See Fig. 5	P_{GM}	16	W
AVERAGE	$P_{G(AV)}$	0.35	W

EMPERATURE RANGE:▲

Storage	T_{stg}	–65 to 150	°C
Operating (Case)	T_C	–65 to 100	°C

ERMINAL TEMPERATURE (During soldering):

For 10 s max. (terminals and case)	T_T	225	°C

LECTRICAL CHARACTERISTICS, *At Maximum Ratings Unless Otherwise Specified, and at Indicated Temperature*

CHARACTERISTIC	SYMBOL	LIMITS For All Types Except as Specified			UNITS
		MIN.	TYP.	MAX.	
ak Off-State Current:● Gate open, T_J = 100°C, V_{DROM} = Max. rated value	I_{DROM}	–	0.1	2	mA
aximum On-State Voltage:● For i_T = 30 A (peak), T_C = 25°C (See Fig. 6)	v_{TM}	–	2	3	V
C Holding Current:● Gate open, Initial principal current = 150 mA (dc) v_D = 12 V, T_C = 25°C	I_{HO}	–	100	–	mA
For other case temperatures			See Fig. 7		
ritical Rate-of-Rise of Commutation Voltage:●▲ For v_D = V_{DROM}, $I_{T(RMS)}$ = 6 A, commutating di/dt = 4.3 A/ms, gate unenergized, T_C = 80°C (See Fig. 12)	dv/dt	2	10	–	V/µs
ritical Rate-of-Rise of Off-State Voltage:● For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 100°C: T2801B	dv/dt	50	300	–	V/µs
T2801C		40	275	–	
T2801D		30	250	–	
T2801E		20	225	–	
C Gate-Trigger Current:●■ Mode V_{MT2} V_G For v_D = 12 V (dc) I+ positive positive	I_{GT}	–	25	80	mA
R_L = 12 Ω T_C = 25°C III– negative negative		–	25	80	
For other case temperatures			See Fig. 9		
C Gate-Trigger Voltage:●■ For v_D = 12 V (dc), R_L = 12 Ω, T_C = 25°C	V_{GT}	–	1.5	4	V
For other case temperatures			See Fig. 10		
For v_D = V_{DROM}, R_L = 125 Ω, T_C = 100°C		0.2	–	–	
ate-Controlled Turn-On Time: (Delay Time + Rise Time) For v_D = V_{DROM}, I_{GT} = 80 mA, t_r = 0.1 µs, i_T = 10 A (peak), T_C = 25°C (See Fig. 13)	t_{gt}	–	2.2	–	µs
hermal Resistance: Junction-to-Case	$R_{\theta JC}$	–	–	2.2	°C/W
Junction-to-Ambient	$R_{\theta JA}$	–	–	60	

For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

For either polarity of gate voltage (V_G) with reference to main terminal 1.

Variants of these devices having dv/dt characteristics selected specifically for inductive loads are available on special order; for additional information, contact your RCA Representative or your RCA Distributor.

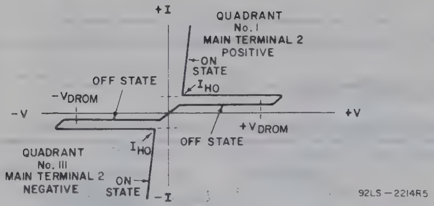


Fig. 1 — Principal voltage-current characteristic.

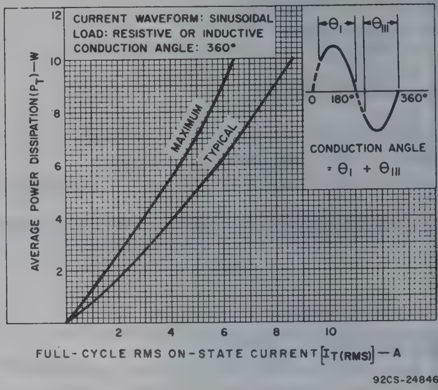


Fig. 2 — Power dissipation vs. on-state current.

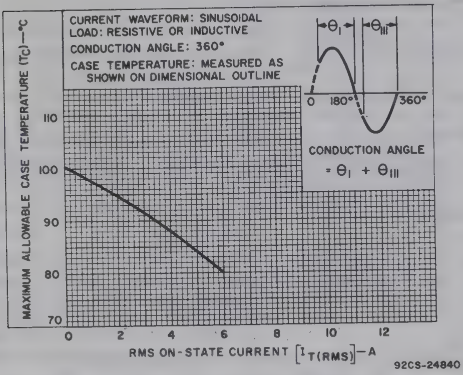


Fig. 3 — Allowable case temperature vs. on-state current.

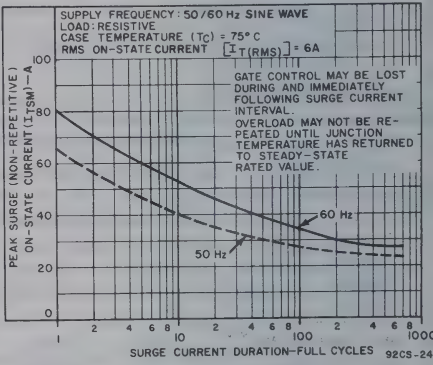


Fig. 4 — Peak surge on-state current vs. surge current duration.

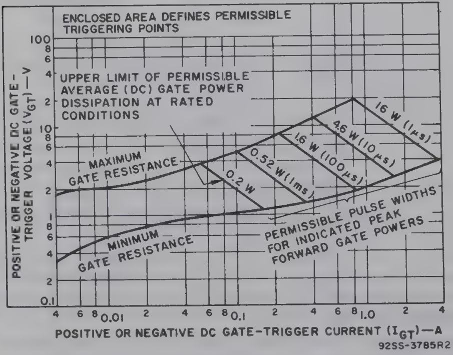


Fig. 5 — Gate pulse characteristics for all triggering modes.

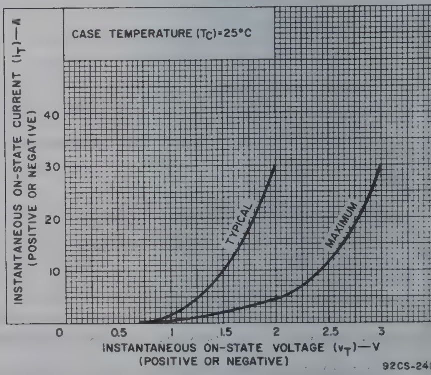


Fig. 6 — On-state current vs. on-state voltage.

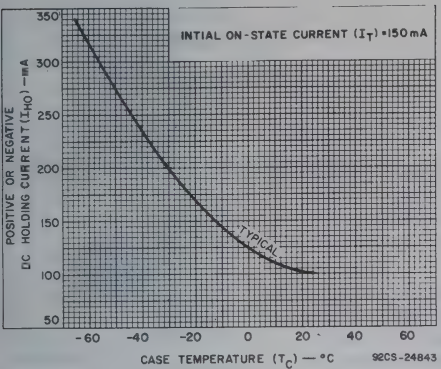


Fig. 7 — DC holding current vs. case temperature.

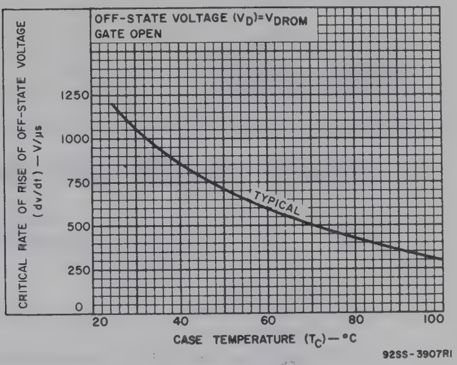


Fig. 8 — Typical critical rate-of-rise of off-state voltage vs. case temperature.

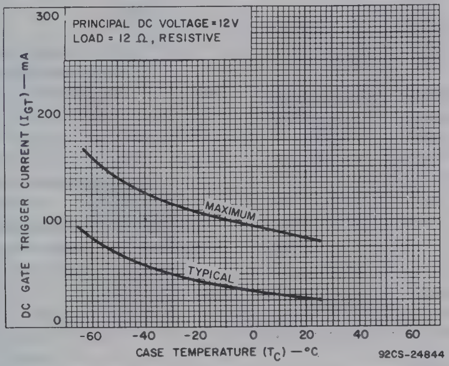


Fig. 9 — DC gate-trigger current (for I^+ and III^- triggering modes) vs. case temperature.

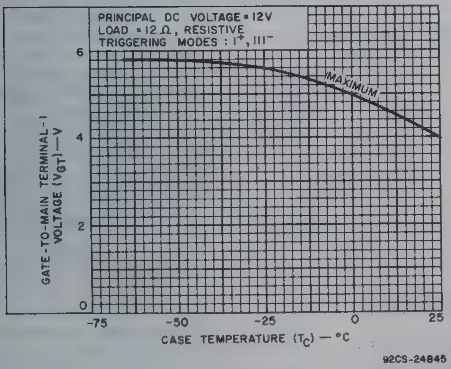


Fig. 10 — DC gate-trigger voltage vs. case temperature.

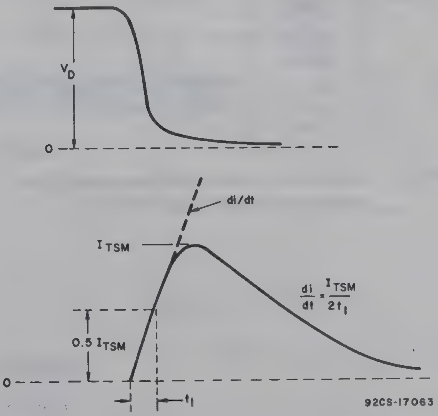

V_D
0
di/dt
I_{TSM}
$\frac{di}{dt} = \frac{I_{TSM}}{2t_1}$
0.5 I_{TSM}
0
t_1
92CS-17063

Fig. 11 — Rate-of-change of on-state current with time (defining di/dt).

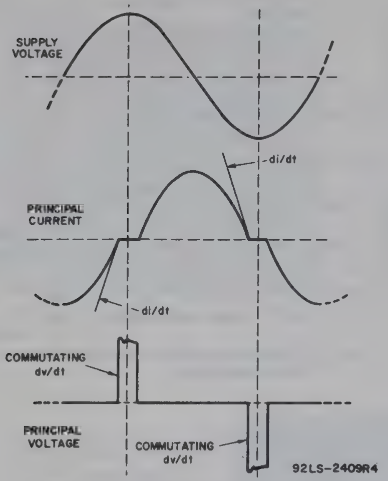


Fig. 12 — Relationship between supply voltage and principal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

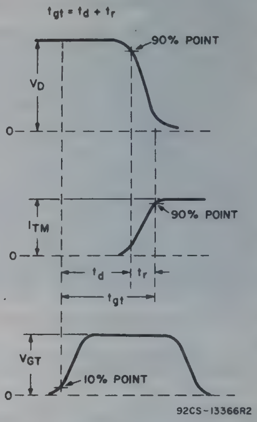


Fig. 13 — Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).

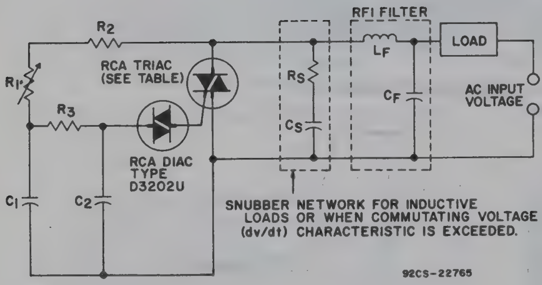

R2
RCA TRIAC (SEE TABLE)
R1
R3
RCA DIAC TYPE D3202U
C1
C2
RS
CS
RFI FILTER
LF
CF
LOAD
AC INPUT VOLTAGE
SNUBBER NETWORK FOR INDUCTIVE LOADS OR WHEN COMMUTATING VOLTAGE (dv/dt) CHARACTERISTIC IS EXCEEDED.
92CS-22765

Fig. 14 — Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.

AC INPUT VOLTAGE		120 V 60 Hz	240 V 60 Hz	240 V 50 Hz
C_1		0.1 µF 200 V	0.1 µF 400 V	0.1 µF 400 V
C_2		0.1 µF 100 V	0.1 µF 100 V	0.1 µF 100 V
R_1		100 kΩ ½ W	200 kΩ ½ W	250 kΩ ½ W
R_2		2.2 kΩ ½ W	3.3 kΩ ½ W	3.3 kΩ ½ W
R_3		15 kΩ ½ W	15 kΩ ½ W	15 kΩ ½ W
SNUBBER NETWORK FOR 6 A (RMS)● INDUCTIVE LOAD	C_S	0.068 µF 200 V	0.1 µF 400 V	0.1 µF 400 V
	R_S	1.2 kΩ ½ W	1 kΩ ½ W	1 kΩ ½ W
RFI FILTER	C_F●	0.1 µF 200 V	0.1 µF 400 V	0.1 µF 400 V
	L_F●	100 µH	200 µH	200 µH
RCA TRIACS		T2801B T2801C	T2801D T2801E	T2801D T2801E

● For other RMS Current values refer to RCA Application Note AN-4745.

● Typical values for Lamp dimming circuits.

TERMINAL CONNECTIONS

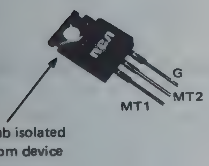
Lead No. 1—Main Terminal 1
Lead No. 2—Main Terminal 2
Lead No. 3—Gate
Mounting Flange—Main Terminal 2

RCA

Solid State
Division

Thyristors

T2850 Series



JEDEC TO-220AB H-1535

8-A Isolated-Tab Silicon Triacs

Three-Lead Plastic Types for
Power-Control and Power-Switching Applications

Features:

- Internal Isolation
- 100-A Peak Surge Full-Cycle Current Ratings
- Shorted-Emitter, Center-Gate Design
- Low Switching Losses
- Low Thermal Resistance
- Package Suitable for Direct Mounting on Heat Sink
- Glass Passivated Junctions

Voltage / Package	100 V Type	200 V Type	400 V Type
TO-220AB	T2850A (40900)	T2850B (40901)	T2850D (40902)

Numbers in parentheses are former RCA type numbers.

he T2850A, T2850B[a], and T2850D[b] triacs are gate-ontrolled full-wave ac switches utilizing a plastic case with hree leads to facilitate mounting on printed-circuit boards. hey are intended for the control of ac loads in such pplications as motor controls, light dimmers, heating ontrols, and power-switching systems.

hese devices are designed to switch from an off-state to an n-state for either polarity of applied voltage with positive or egative gate triggering voltages. They have an on-state cur-ent rating of 8 amperes at a T_C of 75°C and repetitive off-state voltage ratings of 100, 200, and 400 volts, respectively.

The ISOWATT package uses a plastic case with three leads that are electrically isolated from the mounting flange. Because of this internal isolation, the triac can be mounted directly on a heat sink, without any insulating hardware; therefore heat transfer is improved and heat-sink size can be reduced.

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[a] Formerly RCA Dev. No. TA8357

[b] Formerly RCA Dev. No. TA8358

AXIMUM RATINGS, *Absolute-Maximum Values:*

or Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		T2850A	T2850B	T2850D	
EPETITIVE PEAK OFF-STATE VOLTAGE:●					
Gate open, T_J = –65 to 100°C	V_{DROM}	100	200	400	V
MS ON-STATE CURRENT (Conduction angle = 360°):	$I_{T(RMS)}$				
Case temperature T_C = 75°C		8			A
For other conditions		See *Fig. 3*			
EAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}				
For one cycle of applied principal voltage, T_C = 75°C					
60 Hz (sinusoidal)		100			A
50 Hz (sinusoidal)		85			A
For more than one cycle of applied principal voltage		See *Fig. 4*			
ATE OF CHANGE OF ON-STATE CURRENT:					
$V_D = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.1 μs (See Fig. 16)	di/dt	70			A/μs
USING CURRENT (for triac protection):					
T_J = –65 to 100°C, t = 1.25 to 10 ms	I^2t	50			A^2s
PEAK GATE-TRIGGER CURRENT:■					
For 1 μs max.; see *Fig. 11*	I_{GTM}	4			A
GATE POWER DISSIPATION:					
Peak (For 1 μs max., I_{GTM} ≤ 4 A; see *Fig. 11*)	P_{GM}	16			W
AVERAGE	$P_{G(AV)}$	0.2			W
TEMPERATURE RANGE:▲					
Storage	T_{stg}	–65 to 150			°C
Operating (Case)	T_C	–65 to 100			°C
TERMINAL TEMPERATURE (During soldering):					
For 10 s max. (terminals and case)	T_T	225			°C

● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

■ For either polarity of gate voltage (V_G) with reference to main terminal 1.

▲ For temperature measurement reference point, see *Dimensional Outline.*

ELECTRICAL CHARACTERISTICS *At Maximum Ratings Unless Otherwise Specified, and at Indicated Case Temperature (T_C)*

CHARACTERISTIC	SYMBOL	LIMITS									UNITS
		T2850A			T2850B			T2850D			
		MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	
Peak Off-State Current:* Gate Open, V_{DROM} = Max. rated value At T_J = 100°C	I_{DROM}	–	0.1	2	–	0.1	2	–	0.1	2	mA
Maximum On-State Voltage:* For i_T = 30 A (peak) and T_C = 25°C	v_{TM}	–	1.7	2	–	1.7	2	–	1.7	2	V
DC Holding Current:* Gate Open Initial principal current = 150 mA (dc) At T_C = 25°C	I_{HO}	–	15	30	–	15	30	–	15	30	mA
For other case temperatures		See Fig. 8									
Critical Rate of Rise of Commutation Voltage:*♣ For v_D = V_{DROM}, $I_{T(RMS)}$ = 8 A, Commutating di/dt = 4.3 A/ms, and gate unenergized At T_C = 75°C	dv/dt	4	10	–	4	10	–	4	10	–	V/µs
Critical Rate of Rise of Off-State Voltage:* For v_D = V_{DROM}, exponential voltage rise, and gate open At T_C = 100°C	dv/dt	125	350	–	100	300	–	75	250	–	V/µs
For other case temperatures		See Fig. 10									
DC Gate-Trigger Current:*† For v_D = 12 V (dc), R_L = 12Ω T_C = 25°C, and specified triggering mode:	I_{GT}										mA
I⁺ Mode: V_{MT2} is positive, V_G is positive		–	10	25	–	10	25	–	10	25	
III⁻ Mode: V_{MT2} is negative, V_G is negative		–	15	25	–	15	25	–	15	25	
I⁻ Mode: V_{MT2} is positive, V_G is negative		–	20	60	–	20	60	–	20	60	
III⁺ Mode: V_{MT2} is negative, V_G is positive		–	30	60	–	30	60	–	30	60	
For other case temperatures		See Figs. 12 & 13									
DC Gate-Trigger Voltage:*† For v_D = 12 V (dc) and R_L = 12Ω At T_C = 25°C	V_{GT}	–	1.25	2.5	–	1.25	2.5	–	1.25	2.5	V
For other case temperatures		See Fig. 14									
For v_D = V_{DROM} and R_L = 125Ω At T_C = 100°C		0.2	–	–	0.2	–	–	0.2	–	–	
Gate-Controlled Turn-On Time (Delay Time + Rise Time): For v_D = V_{DROM} and I_{GT} = 160 mA rise time = 0.1 µs, and i_T = 10 A (peak) At T_C = 25°C *(See Fig. 15)*	t_{gt}	–	1.6	2.5	–	1.6	2.5	–	1.6	2.5	µs
Thermal Resistance: Junction-to-Case	$R_{\theta JC}$	–	–	3.1	–	–	3.1	–	–	3.1	°C/W
Junction-to-Ambient	$R_{\theta JA}$	–	–	60	–	–	60	–	–	60	°C/W

*For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

†For either polarity of gate voltage (V_G) with reference to main terminal 1.

♣Variants of these devices having dv/dt characteristics selected specifically for inductive loads are available on special order; for additional information, contact your RCA Representative or your RCA Distributor.

TERMINAL CONNECTIONS

Lead No. 1 - Main Terminal 1
Lead No. 2 - Main Terminal 2
Lead No. 3 - Gate
Mounting Tab - Isolated

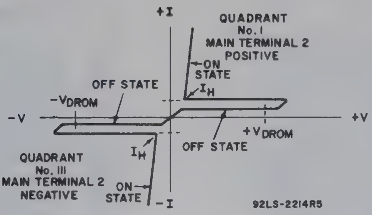


Fig. 1 — Principal voltage-current characteristic.

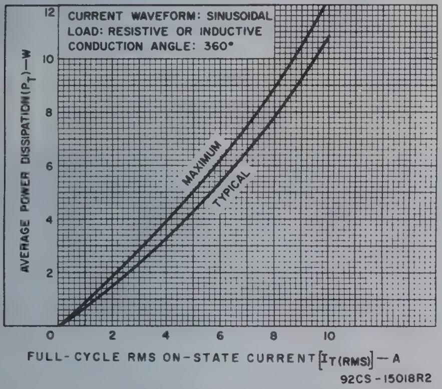


Fig. 2 — Power dissipation vs. on-state current.

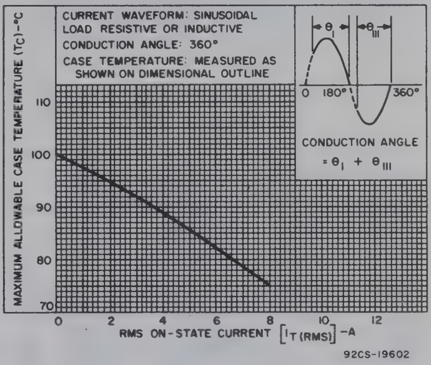


Fig. 3 — Allowable case temperature vs. on-state current.

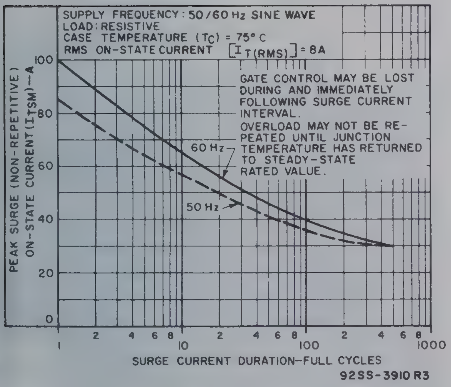


Fig. 4 — Peak surge on-state current vs. surge current duration.

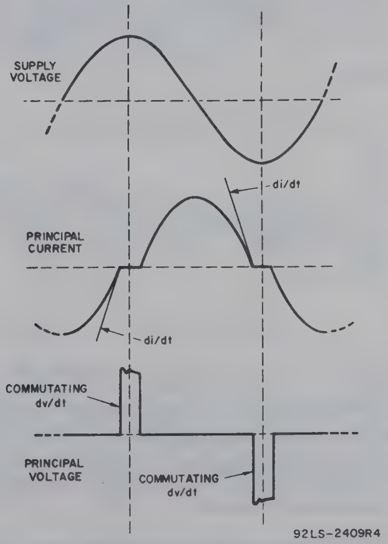

SUPPLY VOLTAGE
-di/dt
PRINCIPAL CURRENT
-di/dt
COMMUTATING dv/dt
PRINCIPAL VOLTAGE
COMMUTATING dv/dt
92LS-2409R4

Fig. 5 — Oscilloscope display of commutating dv/dt.

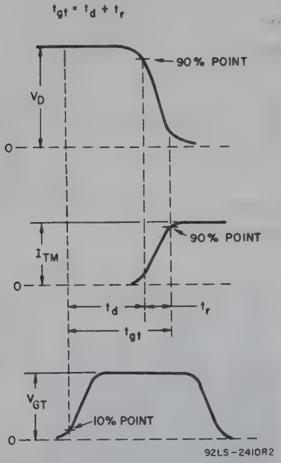
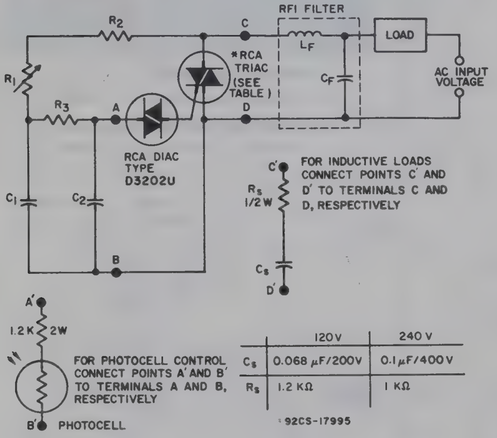

$t_{gt} = t_d + t_r$
90 % POINT
V_D
0
I_{TM}
90 % POINT
0
t_d
t_r
t_{gt}
V_{GT}
10% POINT
0
92LS-2410R2

Fig. 6—Oscilloscope display for measurement of gate-controlled turn-on time (t_{gt}).


RFI FILTER
R2
C
LOAD
L_F
*RCA TRIAC (SEE TABLE)
R_1
C_F
AC INPUT VOLTAGE
R_3
A
D
RCA DIAC TYPE D3202U
C′
FOR INDUCTIVE LOADS CONNECT POINTS C′ AND D′ TO TERMINALS C AND D, RESPECTIVELY
R_s 1/2 W
C_1
C_2
B
C_s
D′
A′
1.2 K 2W
FOR PHOTOCELL CONTROL CONNECT POINTS A′ AND B′ TO TERMINALS A AND B, RESPECTIVELY
B′ PHOTOCELL
92CS-17995

	120 V	240 V
C_s	0.068 μF/200V	0.1 μF/400 V
R_s	1.2 KΩ	1 KΩ

AC INPUT VOLTAGE	C_1	C_2	R_1	R_2	R_3	RFI FILTER		RCA TYPES
						L_F* (typ.)	C_F* (typ.)	
120 V 60 Hz	0.1 μF 200 V	0.1 μF 100 V	100 KΩ ½ W	2.2 KΩ ½ W	15 KΩ ½ W	100 μH	0.1 μF 200V	T2850B
240 V 50 Hz	0.1 μF 400 V	0.1 μF 100 V	250 KΩ 1 W	3.3 KΩ ½ W	15 KΩ ½ W	200 μH	0.1 μF 400 V	T2850D
240 V 60 Hz	0.1 μF 400 V	0.1 μF 100 V	200 KΩ 1 W	3.3 KΩ ½ W	15 KΩ ½ W	200 μH	0.1 μF 400 V	T2850D

*Typical values for lamp-dimming circuits.

Fig. 9—Typical phase-control circuit for lamp dimming, heat controls, and universal motor speed controls.

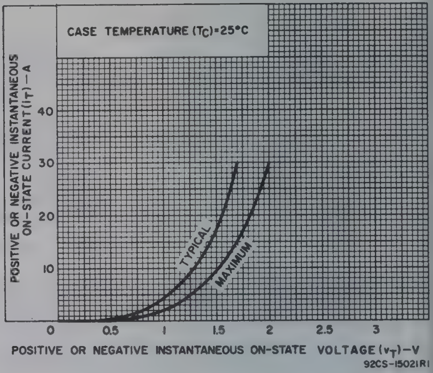


Fig. 7 — On-state current vs. on-state voltage.

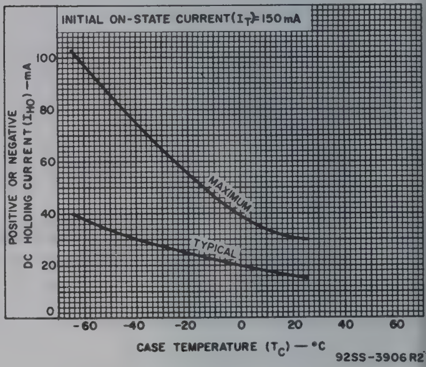


Fig. 8—DC holding current for either direction of on-state current vs. case temperature.

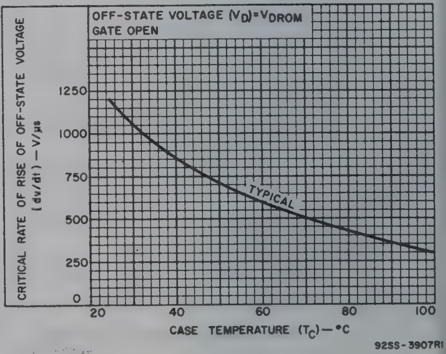


Fig. 10—Critical rate of rise of off-state voltage vs. case temperature.

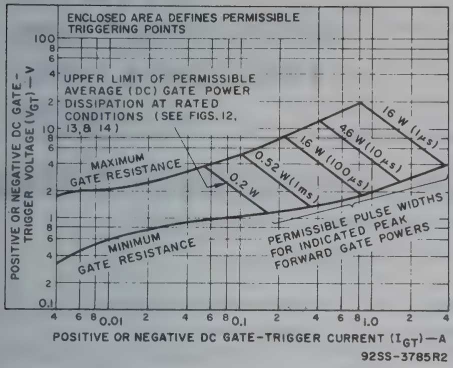


Fig. 11 — Gate-pulse characteristics for all triggering modes.

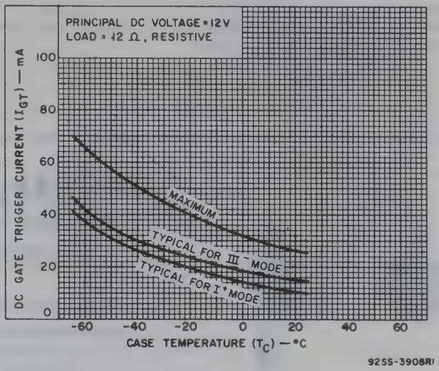


Fig. 12—DC gate-trigger current (for I^+ and III^- triggering modes) vs. case temperature.

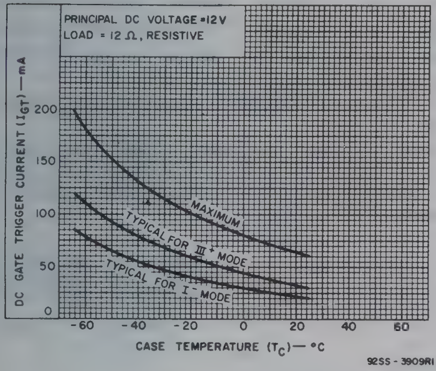


Fig. 13—DC gate-trigger current for I^- and III^+ triggering modes) vs. case temperature.

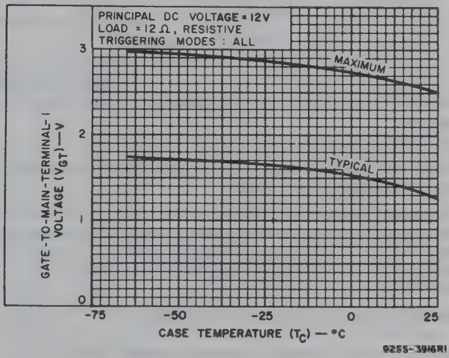


Fig. 14 — DC gate-trigger voltage vs. case temperature.

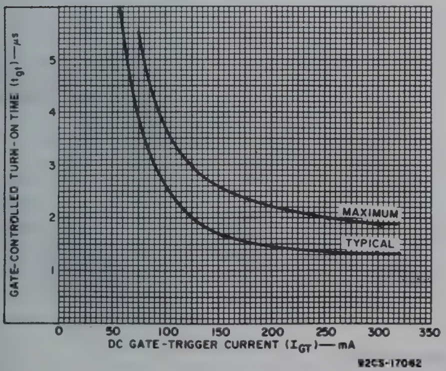


Fig. 15 — Typical turn-on time vs. gate-trigger current.

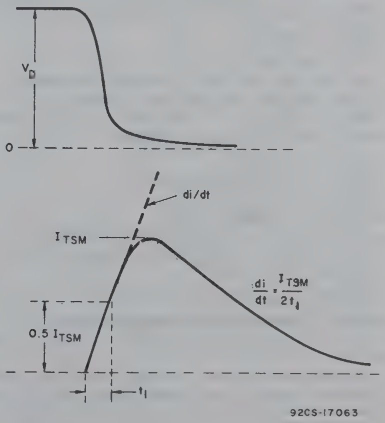
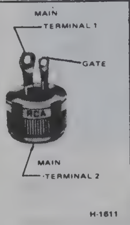

V_D
0
di/dt
I_{TSM}
$\frac{di}{dt} = \frac{I_{TSM}}{2t_1}$
0.5 I_{TSM}
0
t_1
92CS-17063

Fig. 16—Rate of change ot on-state current with time (defining di/dt).

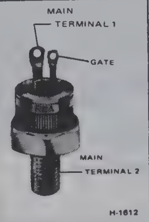
RCA
Solid State Division

Thyristors
T4103 T4104 T4105
T4113 T4114 T4115
Series



T4103 Series
T4104 Series
T4105 Series

PRESS-FIT



T4113 Series
T4114 Series
T4115 Series

STUD

400-Hz, 6,10, & 15-A Silicon Triacs

For Control-Systems Application in Airborne and Ground-Support Type Equipment

Features:

- **di/dt capability = 150 A/μs**
- **Shorted-emitter center-gate design**
- **Commutating dv/dt capability characterized at 400 Hz**

Package / Voltage	Press-fit Types			Stud Types		
200 V Types	T4103B (40783)	T4104B (40779)	T4105B (40775)	T4113B (40785)	T4114B (40781)	T4115B (40777)
400 V Types	T4103D (40784)	T4104D (40780)	T4105D (40776)	T4113D (40786)	T4114D (40782)	T4115D (40778)

Numbers in parentheses are former RCA type numbers.

These RCA triacs are gate-controlled full-wave silicon ac switches.

The devices are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

They are intended for operation up to 400 Hz with resistive or inductive loads and nominal line voltages of 115 and 208 V RMS sine wave and repetitive peak off-state voltages of 200 V and 400 V.

These triacs exhibit commutating voltage (dv/dt) capability at high commutating current (di/dt). They can also be used in 60-Hz applications where high commutating capability is required.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 400 Hz and with Resistive or Inductive Load.

		T4103B T4113B T4104B T4114B T4105B T4115B	T4103D T4113D T4104D T4114D T4105D T4115D	
REPETITIVE PEAK OFF-STATE VOLTAGE:*	V_{DROM}			
Gate open, $T_J = -50$ to 100°C		200	400	V
RMS ON-STATE CURRENT (Conduction angle = 360°):	$I_{T(RMS)}$			
Case temperature				
T_C = 90°C (T4105B, T4105D, T4115B, T4115D)		6		A
= 85°C (T4104B, T4104D, T4114B, T4114D)		10		A
= 80°C (T4103B, T4103D, T4113B, T4113D)		15		A
For other conditions		*See Fig. 3*		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}			
For one cycle of applied principal voltage, T_C as above				
400 Hz (sinusoidal)		200		A
60 Hz (sinusoidal)		100		A
50 Hz (sinusoidal)		85		A
For more than one cycle of applied principal voltage		*See Fig. 4*		
RATE-OF-CHANGE OF ON-STATE CURRENT:	di/dt			
$V_{DM} = V_{DROM}$, I_{GT} = 160 mA, t_r = 0.1 μs *(See Fig. 13)*		150		A/
FUSING CURRENT (for triac protection):				
$T_J = -50$ to 100°C, t = 1.25 to 10 ms	I^2t	30		A^2
PEAK GATE-TRIGGER CURRENT:■	I_{GTM}			
For 1 μs max., *(See Fig. 7)*		4		
GATE POWER DISSIPATION:				
PEAK (For 1 μs max., $I_{GTM} \leq 4$ A, *See Fig. 7)*	P_{GM}	16		
AVERAGE	$P_{G(AV)}$	0.2		
TEMPERATURE RANGE:▲				
Storage	T_{stg}	-50 to 150		°
Operating (Case)	T_C	-50 to 100		°
TERMINAL TEMPERATURE (During soldering):				
For 10 s max. (terminals and case)	T_T	225		°

---

* For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.
▲ For temperature measurement reference point, see Dimensional Outline.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 400 Hz and with Resistive or Inductive Load. (Cont'd.).

T4103B	**T4113B**	**T4103D**	**T4113D**
T4104B	**T4114B**	**T4104D**	**T4114D**
T4105B	**T4115B**	**T4105D**	**T4115D**

STUD TORQUE: τ_S

Recommended	35	in-1b
Maximum (DO NOT EXCEED)	50	in-1b

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC				SYMBOL	LIMITS ALL TYPES			UNITS
					Min.	Typ.	Max.	
Peak Off-State Current:♠ Gate open, T_J = 100°C, V_{DROM} = Max. rated value				I_{DROM}	–	0.1	2	mA
Maximum On-State Voltage:♠ For i_T = 21 A (peak), T_C = 25 °C				V_{TM}	–	1.4	1.8	V
DC Holding Current:♠ Gate open, Initial principal current = 500 mA (DC), v_D = 12 V, T_C = 25° C				I_{HO}	–	20	75	mA
For other case temperatures					See Fig. 6			
Critical Rate-of-Rise of Commutation Voltage:♠ For v_D = V_{DROM}, $I_{T(RMS)}$ = rated value, gate unenergized, (See Fig. 14): Commutating di/dt = 21.4 A/ms, T_C = 90° C T4105B, T4105D, T4115B, T4115D				dv/dt	5	10	–	V/μs
Commutating di/dt = 36 A/ms, T_C = 85° C T4104B, T4104D, T4114B, T4114D					5	10	–	
Commutating di/dt = 53.3 A/ms, T_C = 80° C T4103B, T4103D, T4113B, T4113D					5	10	–	
Critical Rate-of-Rise of Off-State Voltage:♠ For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 100° C				dv/dt	30	150	–	V/μs
DC Gate-Trigger Current:♠†	Mode	V_{MT2}	V_G					
For v_D = 12 V (DC),	I^+	positive	positive	I_{GT}	–	20	50	mA
R_L = 30 Ω, and	III^-	negative	negative		–	20	50	
T_C = 25 °C	I^-	positive	negative		–	35	80	
	III^+	negative	positive		–	35	80	
For other case temperatures					See Figs. 8 & 9			
DC Gate-Trigger Voltage:♠† For v_D = 12 V(DC), R_L = 30Ω, T_C = 25°C				V_{GT}	–	1	2.5	V
For other case temperatures					See Fig. 10			
For v_D = V_{DROM}, R_L = 125Ω, T_C = 100°C					0.2	–	–	
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For v_D = V_{DROM}, I_{GT} = 160mA, t_r = 0.1 μs, i_T = 25A (peak), T_C = 25°C, (See Figs. 11 & 15)				t_{gt}	–	1.6	2.5	μs
Thermal Resistance Steady-State (Junction-to-Case)				$\theta_{J\text{-}C}$	–	–	1	°C/W
Transient (Junction-to-Case)					See Fig. 12			
Steady-State (Junction-to-Ambient)				$\theta_{J\text{-}A}$	–	–	33	°C/W

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

† For either polarity of gate voltage (V_G) with reference to main terminal 1.

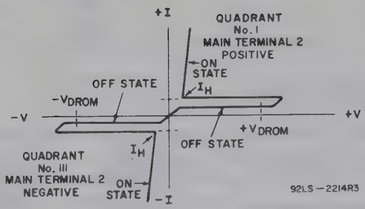

+I
QUADRANT
No. I
MAIN TERMINAL 2
POSITIVE
ON
STATE
OFF STATE
I_H
$-V_{DROM}$
-V
+V
$+V_{DROM}$
OFF STATE
QUADRANT
No. III
MAIN TERMINAL 2
NEGATIVE
I_H
ON
STATE
-I
92LS-2214R3

Fig. 1 – Principal voltage-current characteristic.

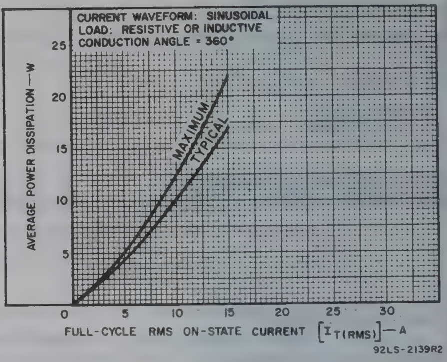


Fig. 2 – Power dissipation vs. on-state current.

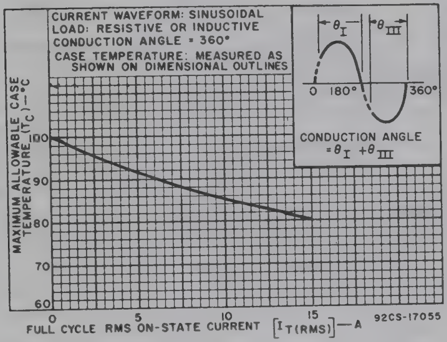


Fig. 3 – Maximum allowable case temperature vs. on-state current.

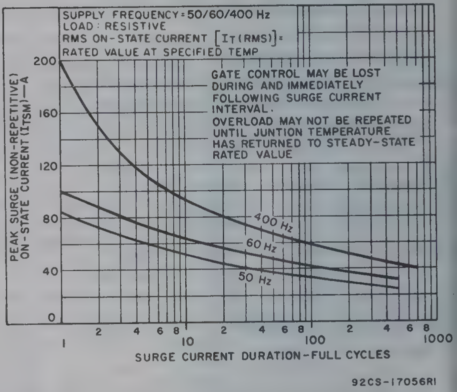


Fig. 4 – Peak surge on-state current vs. surge-current duration.

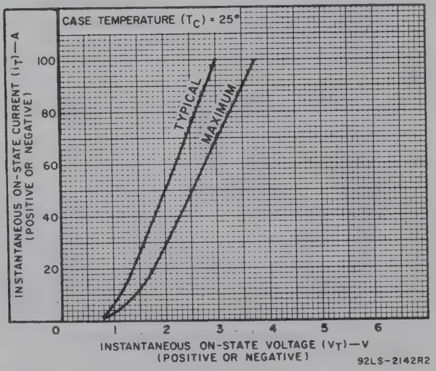


Fig. 5 – On-state current vs. on-state voltage.

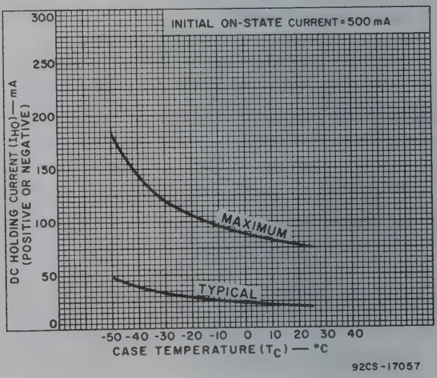


Fig. 6 – DC holding current vs. case temperature.

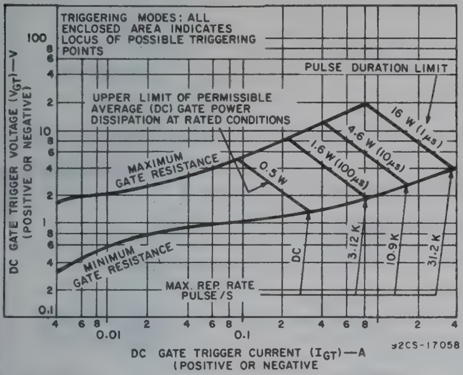


Fig. 7 – Gate trigger characteristics and limiting conditions for determination of permissible gate trigger pulses.

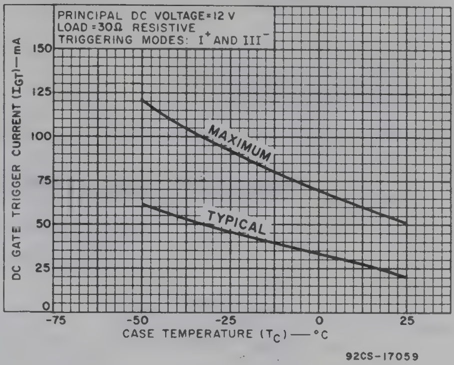


Fig. 8 – DC gate-trigger current vs. case temperature. (I^+ & III^- modes).

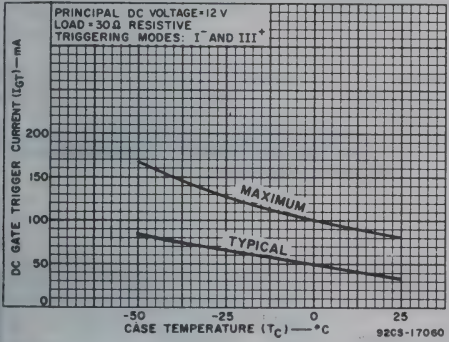


Fig. 9 – DC gate-trigger current vs. case temperature. (I^- & III^+ modes).

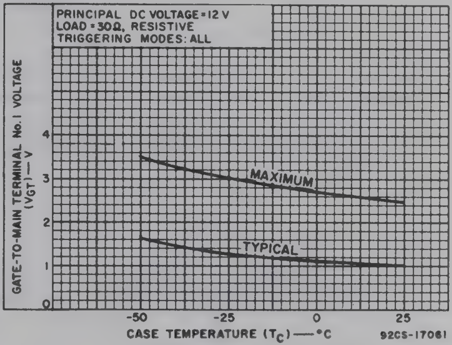


Fig. 10 – DC gate-trigger voltage vs. case temperature.

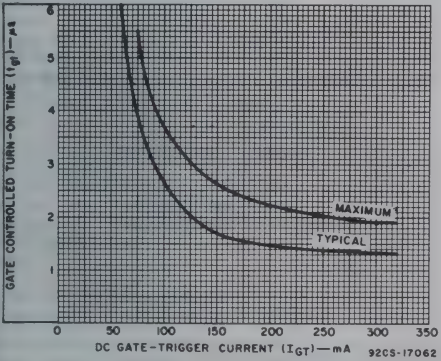


Fig. 11 – Turn-on time vs. gate trigger current.

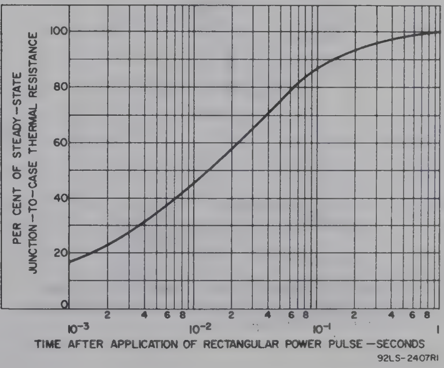


Fig. 12 – Transient thermal resistance vs. time (junction-to-case).

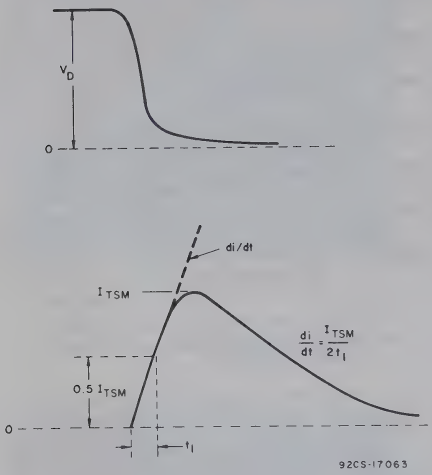


Fig. 13 — Rate of change of on-state current with time (defining di/dt).

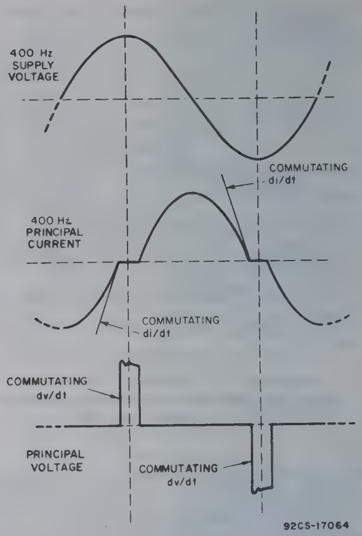


Fig. 14 — Relationship between supply voltage and principal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

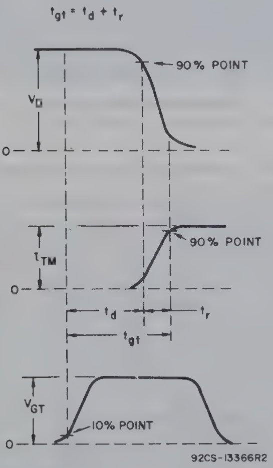


Fig. 15 — Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).

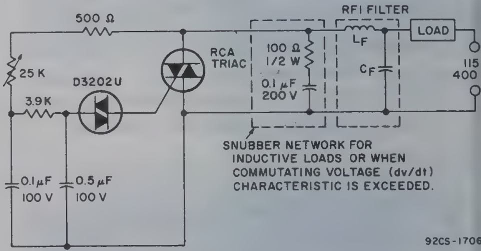

500 Ω
25 K
3.9K
D3202U
RCA TRIAC
100 Ω 1/2 W
0.1 μF 200 V
RFI FILTER
L_F
C_F
LOAD
115
400
0.1μF 100 V
0.5μF 100 V
SNUBBER NETWORK FOR INDUCTIVE LOADS OR WHEN COMMUTATING VOLTAGE (dv/dt) CHARACTERISTIC IS EXCEEDED.
92CS-1706

Fig. 16 — Typical phase-control circuit for operation at 400 Hz.

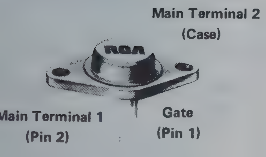
TERMINAL CONNECTIONS

No. 1—Gate
No. 2—Main Terminal 1
Case, No. 3—Main Terminal 2

Solid State
Division

Thyristors

T4700 Series



JEDEC TO-66

H 1340

15-Ampere Silicon Triacs

For Low-Power Phase-Control and Load-Switching Applications

Features:
- di/dt Capability = 150 A/μs
- Shorted-Emitter, Center-Gate Design
- Low Switching Losses
- Low On-State Voltage at High Current Levels
- Low Thermal Resistance

Voltage / Package	200 V Type	400 V Type
TO-66	T4700B (40575)	T4700D (40576)

Numbers in parentheses are former RCA type numbers.

RCA T4700B and T4700D* are gate-controlled full-wave ac licon switches. They are designed to switch from an off-ate to a conducting state for either polarity of applied oltage with positive or negative gate triggering.

These devices are intended for the control of ac loads in applications such as space heater, oven and furnace controls, motor controls, and lamp loads.

---

*Formerly Dev. Types TA2834 and TA2835, respectively.

XIMUM RATINGS, *Absolute-Maximum Values:*

Operation with 50/60-Hz, Sinusoidal Supply Voltage and Resistive or Inductive Load		T4700B	T4700D	
PETITIVE PEAK OFF-STATE VOLTAGE:■				
Gate Open	V_{DROM}	200	400	V
S ON-STATE CURRENT:				
$T_C = 70°C$, conduction angle = 360°	$I_{T(RMS)}$	— 15 —		A
ιK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}			
For one full cycle of applied principal voltage 60 Hz (sinusoidal), $T_C = 70°C$		— 100 —		A
For one full cycle of applied principal voltage (50-Hz, sinusoidal), $T_C = 70°C$		— 85 —		A
For more than one full cycle of applied voltage		See Fig. 6.		
ιK GATE-TRIGGER CURRENT:				
For 1 μs max.	I_{GTM}	— 4 —		A
TE OF CHANGE OF ON-STATE CURRENT:				
$V_D = V_{DROM}$, $I_{GT} = 200$ mA, tr = 0.1 μs (See Fig. 3)	di/dt	— 150 —		A/μs
SING CURRENT (for triac protection):				
$T_J = -40$ to 100°C, t = 1.25 to 10 ms	I^2t	— 50 —		A^2s
TE POWER DISSIPATION:				
Peak● (for 1 μs max. and $I_{GTM} = \leqslant 4$ A)	P_{GM}	— 16 —		W
Average (averaging time = 10 ms max.)	$P_{G(AV)}$	— 0.45 —		W
MPERATURE RANGE:▲				
Storage	T_{stg}	— -40 to 150 —		°C
Operating (Case)	T_C	— -40 to 100 —		°C
TEMPERATURE (During soldering):				
At distances ⩾ 1/32 in. (0.8 mm) from seating plane for 10 s max.	T_p	— 225 —		°C

---

or either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

or either polarity of gate voltage (V_G) with reference to main terminal 1.

or temperature measurement reference point, *see Dimensional Outline.*

Characteristics at Maximum Ratings (unless otherwise specified), and at Indicated Case Temperature (T_C).

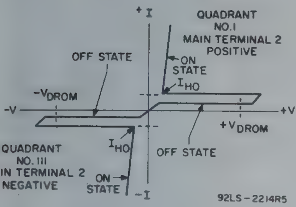
CHARACTERISTICS	TRIAC TYPES						UNITS
	T4700B			T4700D			
	Min.	Typ.	Max.	Min.	Typ.	Max.	
Peak Off-State Current♠, I_{DROM} Gate open At T_j = +100° C and V_{DROM} = Max. rated value	–	0.2	4	–	0.2	4	mA
Instantaneous On-State Voltage♠, v_T For i_T = 30 A (peak) and T_C = +25° C.	–	1.6	2.0	–	1.6	2.0	V(peak)
DC Holding Current♠, I_{HO}: Gate Open Initial principal current = 150 mA (dc) At T_C = +25° C.	–	15	60	–	15	60	mA(dc)
For other case temperatures.		See Fig. 8			See Fig. 8		
Critical Rate of Applied Commutating Voltage♠, Commutating dv/dt: For v_D = V_{DROM}, $I_{T(RMS)}$ = 15 A, commutating di/dt = 8 A/ms, and gate unenergized At T_C = +70° C.	2	10	–	2	10	–	V/μs
Critical Rate of Rise of Off-State Voltage♠, Critical dv/dt: For v_D = V_{DROM}, exponential voltage rise, gate open At T_C = +100° C.	30	150	–	20	100	–	V/μs
DC Gate-Trigger Current♠ ■, I_{GT} For v_D = 6 volts (dc), R_L = 12 ohms, T_C = +25° C, and Specified Triggering Mode:							
I^+ Mode: V_{T2} is positive, V_G is positive. . .	–	15	30	–	15	30	mA(dc)
I^- Mode: V_{T2} is positive, V_G is negative. . .	–	35	80	–	35	80	mA(dc)
III^+ Mode: V_{T2} is negative, V_G is positive. . .	–	35	80	–	35	80	mA(dc)
III^- Mode: V_{T2} is negative, V_G is negative. . .	–	15	30	–	15	30	mA(dc)
For other case temperatures.		See Figs. 12 & 13			See Figs. 12 & 13		
DC Gate-Trigger Voltage♠ ■, V_{GT}: For v_D = 6 volts (dc) and R_L = 12 ohms At T_C = +25° C.	–	1	2.5	–	1	2.5	V(dc)
For other case temperatures.		See Fig. 14			See Fig. 14		
For v_D = V_{DROM} and R_L = 125 ohms At T_C = +100° C.	0.2	–	–	0.2	–	–	V(dc)
Gate-Controlled Turn-On Time, t_{gt} (Delay Time + Rise Time) For v_D = V_{DROM}, I_{GT} = 160 mA, 0.1 μs rise time, and i_T = 25 A (peak) At T_C = +25° C.	–	1.6	2.5	–	1.6	2.5	μs
Thermal Resistance, Junction to case, $R_{\theta JC}$	–	–	1.3	–	–	1.3	°C/W

♠For either polarity of main terminal 2 voltage (V_{T2}) with reference to main terminal 1.

■For either polarity of gate voltage (V_G) with reference to main terminal 1.

TERMINAL CONNECTIONS

Pin 1: Gate
Pin 2: Main Terminal 1
Case: Main Terminal 2


+I
QUADRANT
NO. I
MAIN TERMINAL 2
POSITIVE
OFF STATE
ON
STATE
I_{HO}
$-V_{DROM}$
-V
+V
$+V_{DROM}$
QUADRANT
NO. III
IN TERMINAL 2
NEGATIVE
I_{HO}
OFF STATE
ON
STATE
-I
92LS-2214R5

1 - Principal voltage-current characteristic.

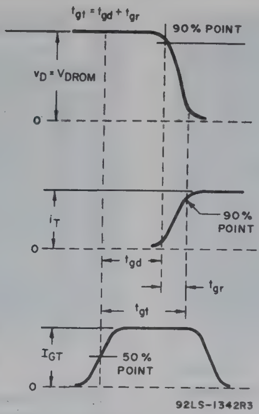

$t_{gt} = t_{gd} + t_{gr}$
90% POINT
$v_D = V_{DROM}$
0
i_T
90%
POINT
0
t_{gd}
t_{gr}
t_{gt}
I_{GT}
50%
POINT
0
92LS-1342R3

Fig. 2—Waveshapes of t_{gt} characteristics test.

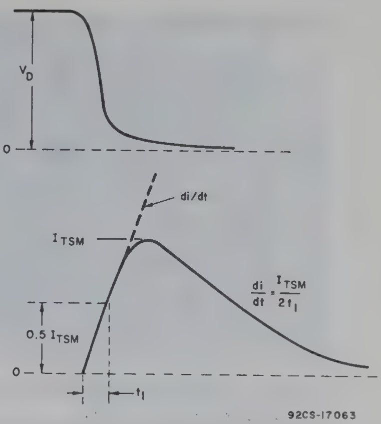
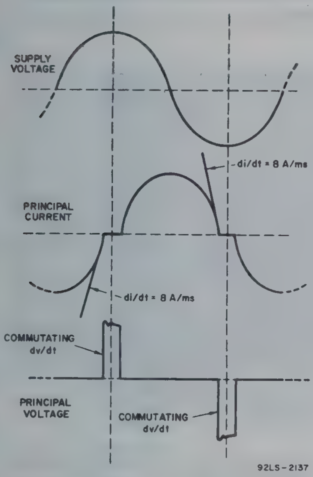

V_D
0
di/dt
I_{TSM}
$\frac{di}{dt} = \frac{I_{TSM}}{2t_1}$
$0.5\ I_{TSM}$
0
t_1
92CS-17063

Fig. 3—Rate of change of on-state current with time (defining di/dt).


SUPPLY
VOLTAGE
-di/dt = 8 A/ms
PRINCIPAL
CURRENT
-di/dt = 8 A/ms
COMMUTATING
dv/dt
PRINCIPAL
VOLTAGE
COMMUTATING
dv/dt
92LS-2137

. 4—Waveshapes of commutating dv/dt characteristics.

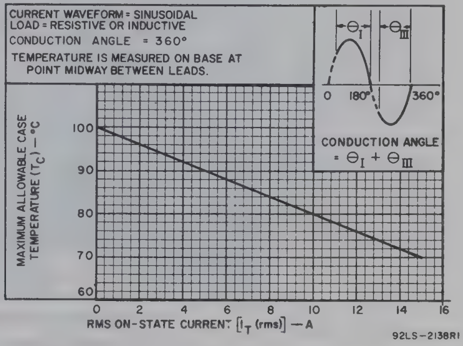


Fig. 5— Conduction rating chart (case temperature).

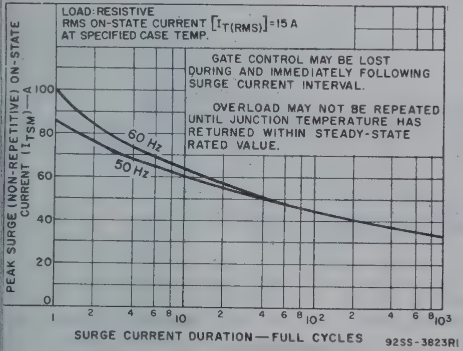


Fig. 6—Surge current rating chart.

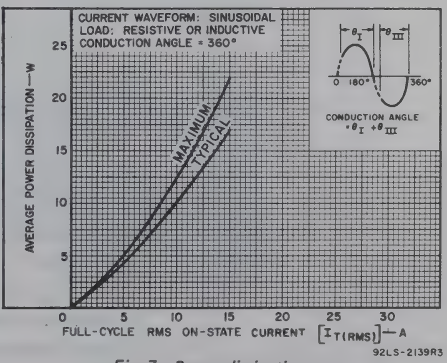


Fig. 7— Power dissipation curve.

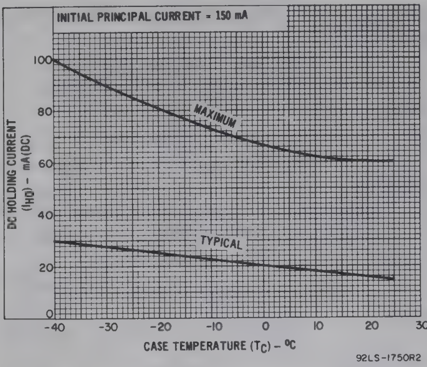


Fig. 8 - DC holding current characteristics for either direction of principal current.

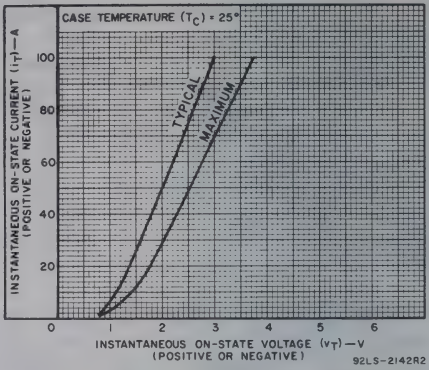


Fig. 9— On-state characteristics for either direction of principal current.

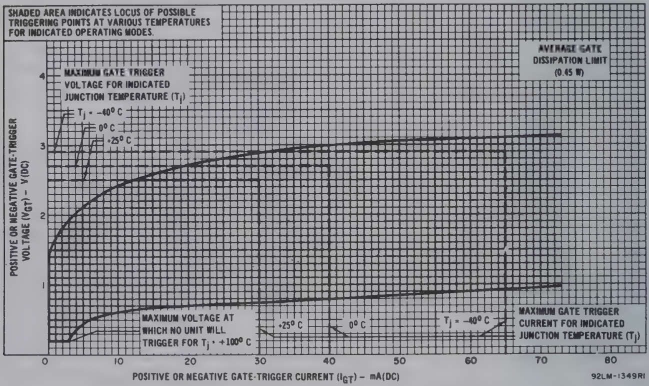


Fig. 10— Gate characteristics for I^+ and III^+ triggering modes.

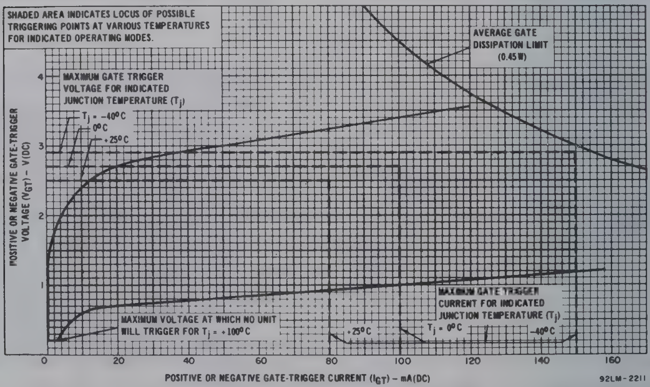


Fig. 11— Gate characteristics for I^- and III^+ triggering modes.

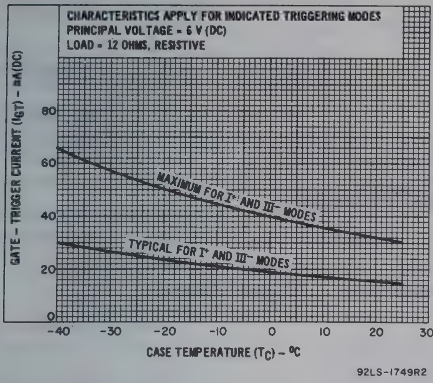


Fig. 12 - DC gate-trigger current characteristics for I^+ and III^- modes.

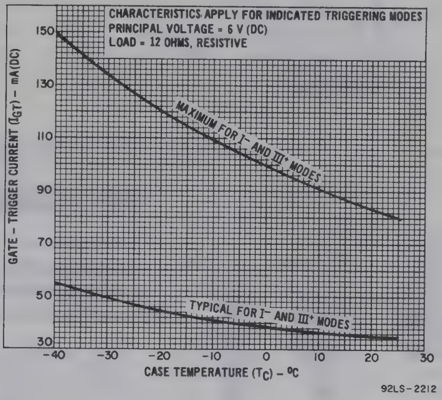


Fig. 13 - DC gate-trigger current characteristics for I^- and III^+ modes.

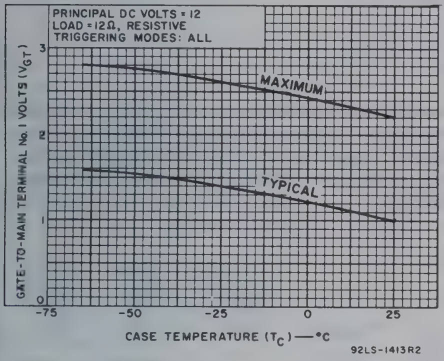


Fig. 14 - DC gate-trigger voltage characteristics.

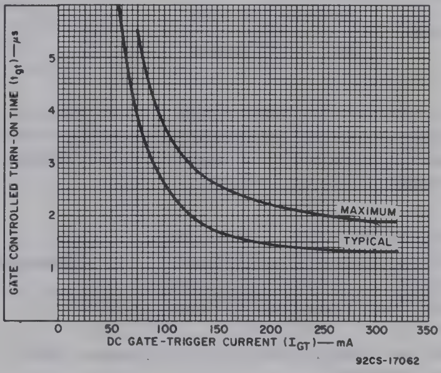
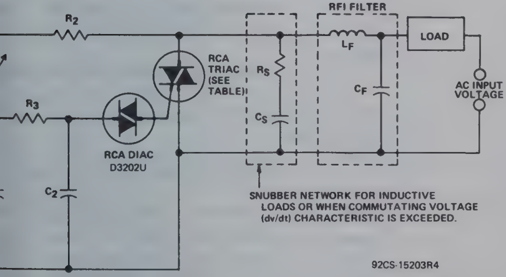


Fig. 15— Turn-on time vs. gate trigger current.


R2
R3
C2
RCA DIAC
D3202U
RCA TRIAC (SEE TABLE)
RS
CS
RFI FILTER
LF
CF
LOAD
AC INPUT VOLTAGE
SNUBBER NETWORK FOR INDUCTIVE LOADS OR WHEN COMMUTATING VOLTAGE (dv/dt) CHARACTERISTIC IS EXCEEDED.
92CS-15203R4

ig. 16— Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.

AC INPUT VOLTAGE		120 V 60 Hz	240 V 60 Hz	240 V 50 Hz
C_1		0.1 µF 200 V	0.05 µF 400 V	0.05 µF 400 V
C_2		0.1 µF 100 V	0.1 µF 100 V	0.1 µF 100 V
R_1		100 KΩ ½ W	200 KΩ 1 W	200 KΩ 1 W
R_2		1 KΩ ½ W	7.5 KΩ 2 W	7.5 KΩ 2 W
R_3		15 KΩ ½ W	7.5 KΩ 2 W	7.5 KΩ 2 W
SNUBBER NETWORK FOR 15-A (RMS)● INDUCTIVE	C_S	0.1 µF 200 V	0.1 µF 400 V	0.1 µF 400 V
	R_S	100 Ω ½ W	100 Ω ½ W	100 Ω ½ W
RFI FILTER	C_F*	0.1 µF 200 V	0.1 µF 400 V	0.1 µF 400 V
	L_F*	100 µH	100 µH	100 µH
RCA TRIAC		T4700B	T4700D	T4700D

● For other RMS current values refer to RCA Application Note AN-4745.

* Typical values for lamp dimming circuits.

RCA
Solid State Division

Thyristors

T6401 T6411 T6421 Series

Main Terminal 1
Gate
H-1600
Main Terminal 2

T6401 Series

Press-fit

Main Terminal 1
Gate
H-1601
Main Terminal 2

T6411 Series

Stud

Main Terminal 1
Gate
H-1689
Main Terminal 2

T6421 Series

Isolated-stud

30-A Silicon Triacs

Features:

- di/dt Capability = 100 A/µs
- Shorted-Emitter Center-Gate Design
- Low Switching Losses
- Low On-State Voltage at High Current Levels
- Low Thermal Resistance

Voltage / Package	200 V Types	400 V Types	600 V Types
Pressfit	T6401B (40660)	T6401D (40661)	T6401M (40671)
Stud	T6411B (40662)	T6411D (40663)	T6411M (40672)
Isolated-Stud	T6421B (40805)	T6421D (40806)	T6421M (40807)

Numbers in parentheses are former RCA type numbers.

These RCA triacs are gate-controlled full-wave silicon ac switches. They are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

These triacs are intended for control of ac loads in applications such as heating controls, motor controls, arc-welding equipment, light dimmers, and power switching systems. They can also be used in air-conditioning and photocopying equipment.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		T6401B T6411B T6421B	T6401D T6411D T6421D	T6401M T6411M T6421M	
REPETITIVE PEAK OFF-STATE VOLTAGE:●					
Gate open, T_J = −50 to 100° C	V_{DROM}	200	400	600	V
RMS ON-STATE CURRENT (Conduction angle = 360°):	$I_{T(RMS)}$				
Case temperature T_C = 65° C (Press-fit types)		30			A
= 60° C (Stud types)		30			A
= 55° C (Isolated-stud types)		30			A
For other conditions		*See Fig. 3*			
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}				
For one cycle of applied principal voltage, T_C as above					
60 Hz (sinusoidal)		300			A
50 Hz (sinusoidal)		265			A
For more than one cycle of applied principal voltage		See *Fig. 4*			
RATE-OF-CHANGE OF ON-STATE CURRENT:	di/dt				
$V_{DM} = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.1 µs (See *Fig. 13*)		100			A/µs
FUSING CURRENT (for triac protection):					
T_J = -40 to 100° C, t = 1.25 to 10 ms	I^2t	450			A^2s
PEAK GATE-TRIGGER CURRENT:■	I_{GTM}				
For 1 µs max., See *Fig. 7*		12			A
GATE POWER DISSIPATION:					
PEAK (For 1 µs max., $I_{GTM} \leq 4$ A, See *Fig. 7*)	P_{GM}	40			W
AVERAGE	$P_{G(AV)}$	0.75			W
TEMPERATURE RANGE:▲					
Storage	T_{stg}	−65 to 150			°C
Operating (Case)	T_C	−65 to 100			°C
TERMINAL TEMPERATURE (During soldering):	T_T				
For 10 s max. (terminals and case)		225			°C

AXIMUM RATINGS, *Absolute-Maximum Values:*
or Operation with Sinusoidal Supply Voltage at Frequencies up to 0/60 Hz and with Resistive or Inductive Load.

	T6401B T6411B T6421B	T6401D T6411D T6421D	T6401M T6411M T6421M	
TUD TORQUE:				
Recommended		35		in-lb
Maximum (DO NOT EXCEED)		50		in-lb

For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
For either polarity of gate voltage (V_G) with reference to main terminal 1.
For temperature measurement reference point, see Dimensional Outline.

LECTRICAL CHARACTERISTICS
: Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	SYMBOL	LIMITS			UNITS
		Min.	Typ.	Max.	
eak Off-State Current:♠					
Gate open, $T_J = 100^o$ C, V_{DROM} = Max. rated value	I_{DROM}	–	0.2	4	mA
aximum On-State Voltage:♠					
For i_T = 100 A (peak), $T_C = 25^o$ C	V_{TM}	–	2.1	2.5	V
C Holding Current:♠					
Gate open, Initial principal current = 150 mA (DC), v_D = 12V: $T_C = 25^o$ C	I_{HO}	–	25	60	mA
For other case temperatures			See *Fig. 6*		
ritical Rate-of-Rise of Commutation Voltage:♠					
For $v_D = V_{DROM}$, $I_{T(RMS)}$ = 30 A, commutating di/dt = 16 A/ms, gate unenergized, (See *Fig. 14*): $T_C = 65^o$ C (Press-fit types)	dv/dt	3	20	–	V/μs
= 60^o C (Stud types)		3	20	–	
= 55^o C (Isolated-stud types)		3	20	–	
ritical Rate-of-Rise of Off-State Voltage:♠					
For $v_D = V_{DROM}$, exponential voltage rise, gate open, $T_C = 100^o$ C: T6401B, T6411B, T6421B	dv/dt	40	200	–	V/μs
T6401D, T6411D, T6421D		25	150	–	
T6401M, T6411M, T6421M		20	100	–	
C Gate-Trigger Current:♠♦ Mode / V_{MT2} / V_G					
For v_D = 12 V (DC), $R_L = 30\ \Omega$, $T_C = 25^o$ C — I+ positive positive	I_{GT}	–	15	50	mA
III- negative negative		–	20	50	
I- positive negative		–	30	80	
III+ negative positive		–	40	80	
For other case temperatures			See *Figs. 8 & 9*		
C Gate-Trigger Voltage:♠♦					
For v_D = 12 V(DC), $R_L = 30\ \Omega$, $T_C = 25^o$ C	V_{GT}	–	1.35	2.5	V
For other case temperatures			See *Fig. 10*		
For $v_D = V_{DROM}$, $R_L = 125\ \Omega$, $T_C = 100^o$ C		0.2	–	–	
ate-Controlled Turn-On Time: (Delay Time + Rise Time)					
For $v_D = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.1 μs, i_T = 45 A (peak), $T_C = 25^o$ C (See *Figs. 11 & 15*)	t_{gt}	–	1.7	3	μs
hermal Resistance, Junction-to-Case:					
Steady-State: Press-fit types	$\theta_{J\text{-}C}$	–	–	0.8	°C/W
Stud		–	–	0.9	
Transient (Press-fit & stud types)			See *Fig. 12*		
hermal Resistance, Junction-to-Hex (Stud, See Dim. Outline):					
Steady-State (Isolated-stud types)	$\theta_{J\text{-}IH}$	–	–	1	

or either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
or either polarity of gate voltage (V_G) with reference to main terminal 1.

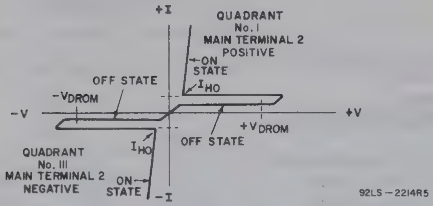


Fig. 1 – Principal voltage-current characteristic.

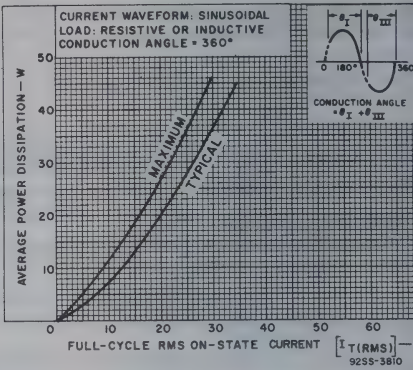


Fig. 2 – Power dissipation vs. on-state current.

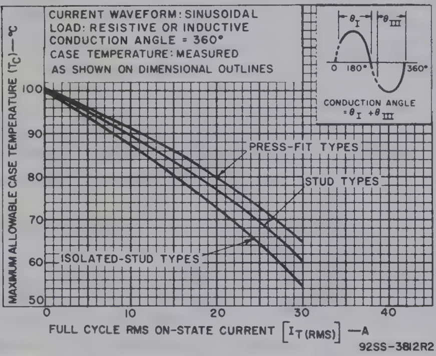


Fig. 3 – Maximum allowable case temperature vs. on-state current.

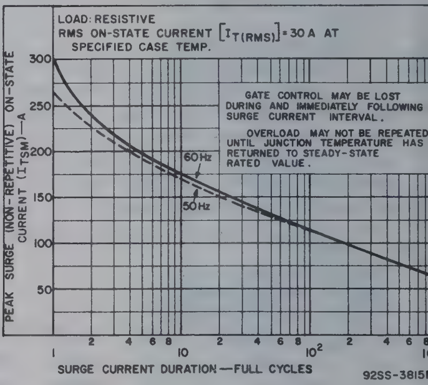


Fig. 4 – Peak surge on-state current vs. surge current duration.

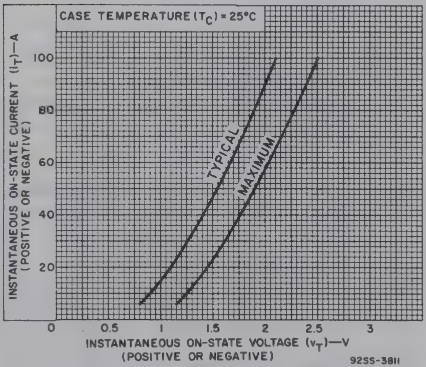


Fig. 5 – On-state current vs. on-state voltage.

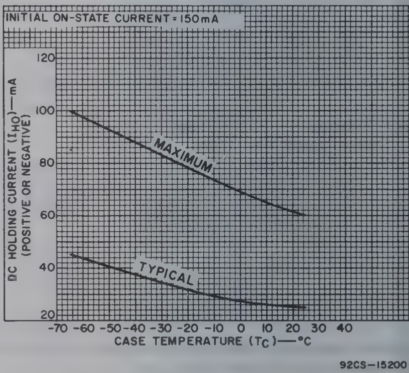


Fig. 6 – DC holding current vs. case temperature.

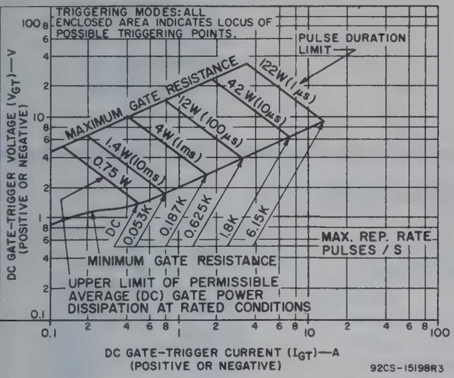


Fig. 7 – Gate trigger characteristics and limiting conditions for determination of permissible gate trigger pulses.

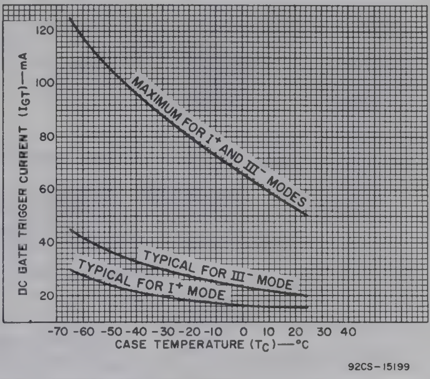


Fig. 8 – DC gate-trigger current vs. case temperature (1+ & III- modes).

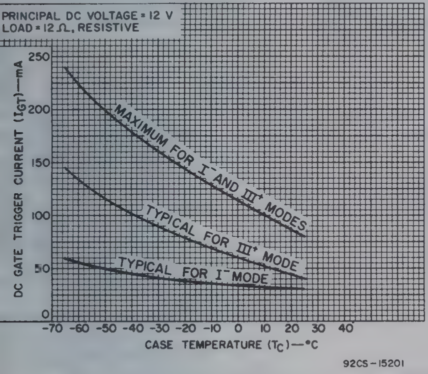


Fig. 9 – DC gate-trigger current vs. case temperature (1- & III+ modes).

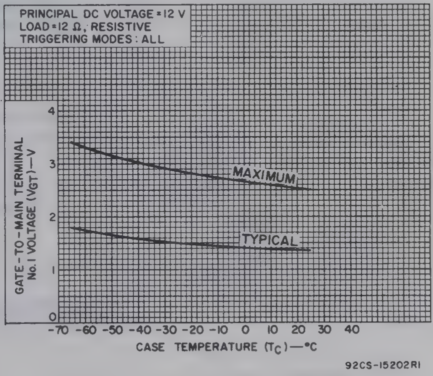


Fig. 10 – DC gate-trigger voltage vs. case temperature.

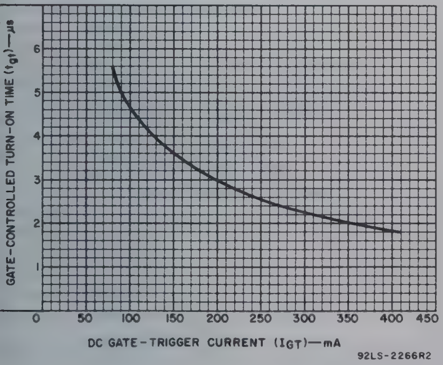


Fig. 11 – Turn-on time vs. gate trigger current.

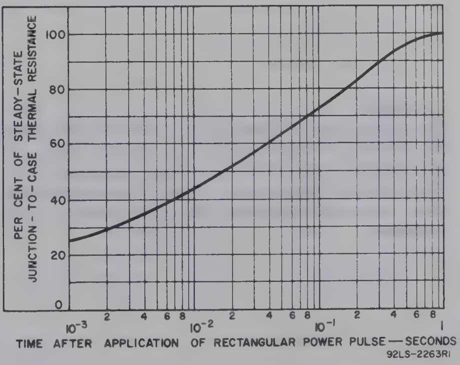


Fig. 12 – Transient junction-to-case thermal resistance vs. time.

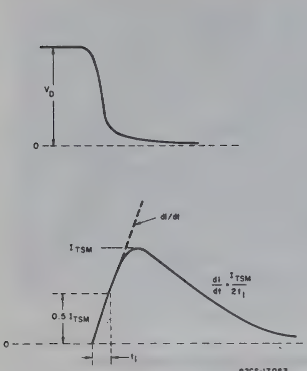


Fig. 13 — Rate of change of on-state current with time (defining di/dt).

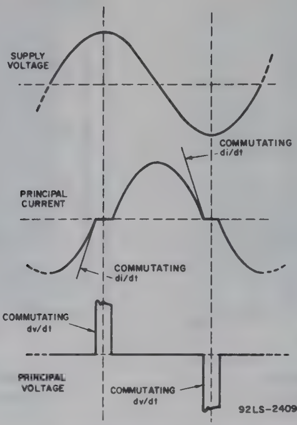


Fig. 14 — Relationship between supply voltage and principle current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

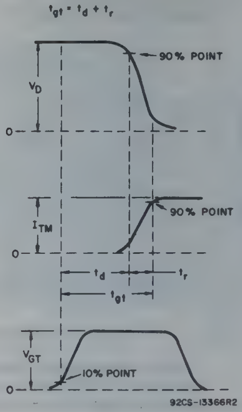


Fig. 15 — Relationship between off-state voltage on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).

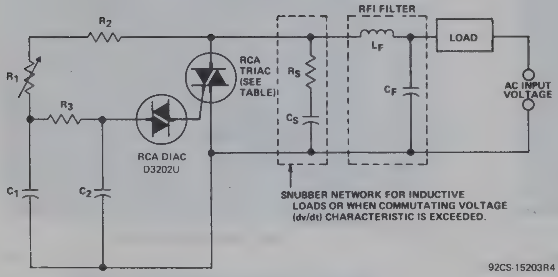

RFI FILTER
R_2
L_F
LOAD
R_1
RCA TRIAC (SEE TABLE)
R_S
C_F
AC INPUT VOLTAGE
R_3
C_S
RCA DIAC D3202U
C_1
C_2
SNUBBER NETWORK FOR INDUCTIVE LOADS OR WHEN COMMUTATING VOLTAGE (dv/dt) CHARACTERISTIC IS EXCEEDED.
92CS-15203R4

Fig. 16 — Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.

AC INPUT VOLTAGE		120V 60Hz	240V 60Hz	240V 50Hz
C_1		0.1µF 200V	0.1µF 400V	0.1µF 400V
C_2		0.1µF 100V	0.1µF 100V	0.1µF 100V
R_1		100KΩ 1/2W	200KΩ 1W	250KΩ 1W
R_2		2.2KΩ 1/2W	3.3KΩ 1/2W	3.3KΩ 1/2W
R_3		15KΩ 1/2W	15KΩ 1/2W	15KΩ 1/2W
SNUBBER NETWORK	C_S	0.1µF 200V	0.1µF 400V	0.1µF 400V
	R_S	100Ω 1/2W	100Ω 1/2W	100Ω 1/2W
RFI FILTER	C_F*	0.1µF 200V	0.1µF 400V	0.1µF 400V
	L_F*	100µH	200µH	200µH
RCA TRIACS		T6401B T6411B T6421B	T6401D T6411D T6421D	T6401D T6411D T6421D

*Typical values for lamp dimming circuits.

WARNING:
The RCA isolated-stud package thyristors should be handled with care. The ceramic portion of these thyristors contains BERYLLIUM OXIDE as a major ingredient. Do not crush, grind, or abrade these portions of the thyristors because the dust resulting from such action may be hazardous if inhaled.

TERMINAL CONNECTIONS

No.1—Gate
No.2—Main Terminal 1
Case, No.3—Main Terminal 2

RCA
Solid State Division

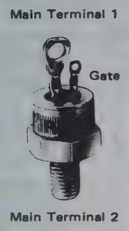
Thyristors

T6404 T6405
T6414 T6415
Series

Main Terminal 1
Gate
Main Terminal 2

T6404 Series
T6405 Series

Press-fit H-1600



T6414 Series
T6415 Series

Stud H-1601

400-Hz, 25 & 40-A Silicon Triacs

For Control-Systems Application in Airborne and Ground-Support Type Equipment

Features:

- **RMS On-State Current —**
  $I_{T(RMS)}$ = 25A: T6405 and T6415 Series
  = 40A: T6404 and T6414 Series
- **Commutating dv/dt Capability Characterized at 400 Hz**
- **Shorted-Emitter Center-Gate Design**
- **di/dt Capability = 100 A/µs**

Voltage Package	200 V Types	400 V Types
Press-fit	T6404B (40791)	T6404D (40792)
Press-fit	T6405B (40787)	T6405D (40788)
Stud	T6414B (40793)	T6414D (40794)
Stud	T6415B (40789)	T6415D (40790)

Numbers in parentheses are former RCA Type numbers.

hese RCA triacs are gate-controlled full-wave silicon ac witches. They are designed to switch from an off-state to an n-state for either polarity of applied voltage with positive negative gate triggering voltages.

hey are intended for operation at 400 Hz with resistive inductive loads and nominal line voltages of 115 and 208 V RMS sine wave and repetitive peak off-state voltages of 200 V and 400 V.

These triacs exhibit commutating voltage (dv/dt) capability at high commutating current (di/dt). They can also be used in 60-Hz applications where high commutating capability is required.

AXIMUM RATINGS, *Absolute-Maximum Values:*
or Operation with Sinusoidal Supply Voltage at 400 Hz and with Resistive or Inductive Load.

		T6404B T6405B T6414B T6415B	T6404D T6405D T6414D T6415D	
EPETITIVE PEAK OFF-STATE VOLTAGE:*	V_{DROM}			
Gate open, T_J = –50 to 110° C		200	400	V
MS ON-STATE CURRENT (Conduction Angle = 360°):	$I_{T(RMS)}$			
Case temperature				
T_C = 85° C (T6405 Series)		25		A
80° C (T6415 Series)		25		A
70° C (T6404 Series)		40		A
65° C (T6414 Series)		40		A
For other conditions		*See Fig.3*		
EAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}			
For one cycle of applied principal voltage, T_C as above				
400 Hz (sinusoidal)		600		A
60 Hz (sinusoidal)		300		A
50 Hz (sinusoidal)		265		A
For more than one cycle of applied principal voltage		*See Fig.4*		
ATE-OF-CHANGE OF ON-STATE CURRENT:	di/dt			
$V_{DM} = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.1 µs *(See Fig. 15)*		100		A/µs
USING CURRENT (for Triac Protection):	I^2t			
T_J = –50 to 110° C, t = 1.25 to 10 ms		270		A^2s
EAK GATE-TRIGGER CURRENT:■	I_{GTM}			
For 1 µs max. *(See Fig. 7)*		12		A
ATE POWER DISSIPATION:				
Peak (For 10 µs max., $I_{GTM} \leq$ 4 A (peak), *(See Fig. 7)*	P_{GM}	42		W
Average	$P_{G(AV)}$	0.75		W
EMPERATURE RANGE:▲				
Storage	T_{stg}	–50 to 150		°C
Operating (Case)	T_C	–50 to 110		°C
ERMINAL TEMPERATURE (During soldering):	T_T			
For 10 s max. (terminals and case)		225		°C

For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
For either polarity of gate voltage (V_G) with reference to main terminal 1.
For temperature measurement reference point, see Dimensional Outline.

MAXIMUM RATINGS, *Absolute-Maximum Values:* (Cont'd) *For Operation with Sinusoidal Supply Voltage at 400 Hz and with Resistive or Inductive Load.*		**T6404B** **T6405B** **T6414B** **T6415B**	**T6404D** **T6405D** **T6414D** **T6415D**	
STUD TORQUE:				
Recommended	τ_s	35		in.-l
Maximum (DO NOT EXCEED)		50		in.-l

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	SYMBOL	LIMITS			UNITS
		Min.	Typ.	Max.	
Peak Off-State Current:●					
Gate open, T_J = 110° C, V_{DROM} = Max. rated value	I_{DROM}	–	0.2	4	mA
Maximum On-State Voltage:●					
For i_T = 100 A (peak), T_C = 25° C:	V_{TM}				V
T6405 & T6415 Series		–	1.7	2.5	
T6404 & T6414 Series		–	1.7	2	
DC Holding Current:●					
Gate open, Initial principal current = 500 mA (DC), v_D = 12 V, T_C = 25° C	I_{HO}	–	30	90	mA
For other case temperatures		See Fig.6			
Critical Rate-of-Rise of Commutation Voltage:●					
For v_D = V_{DROM}, $I_{T(RMS)}$ = rated value, gate unenergized, (See Figs.13 & 14):	dv/dt				V/µs
Commutating di/dt = 88 A/ms					
T_C = 85° C (T6405 Series)		2	–	–	
= 80° C (T6415 Series)		2	–	–	
Commutating di/dt = 141 A/ms					
T_C = 70° C (T6404 Series)		2	–	–	
= 65° C (T6414 Series)		2	–	–	
Critical Rate-of-Rise of Off-State Voltage:●					
For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 110° C:	dv/dt				V/µs
T6405 & T6415 Series		30	150	–	
T6404 & T6414 Series		50	200	–	
DC Gate-Trigger Current:●† — Mode, V_{MT2}, V_G					
For v_D = 12 V (DC), R_L = 30 Ω, T_C = 25° C — I^+, positive, positive	I_{GT}	–	20	80	mA
III^-, negative, negative		–	50	80	
I^-, positive, negative		--	80	120	
III^+, negative, positive		–	80	120	
For other case temperatures		See Figs.8 & 9			
DC Gate-Trigger Voltage:●†					
For v_D = 12 V(DC), R_L = 30 Ω, T_C = 25° C	V_{GT}	–	2	3	V
For other case temperatures		See Fig. 10			
For v_D = V_{DROM}, R_L = 125 Ω, T_C = 110° C		0.2	–	–	
Gate-Controlled Turn-On Time: (Delay Time + Rise Time)					
For v_D = V_{DROM}, I_{GT} = 150 mA, t_r = 0.1 µs, i_T = 60 A (peak), T_C = 25° C (See Figs. 11 & 12)	t_{gt}	–	1.6	2.5	µs
Thermal Resistance, Junction-to-Case:					
Steady-State	$\theta_{J\text{-}C}$				°C/W
Press-fit types		–	–	0.8	
Stud		–	–	0.9	
Transient (Press-fit & stud types)		See Fig. 16			

● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

† For either polarity of gate voltage (V_G) with reference to main terminal 1.

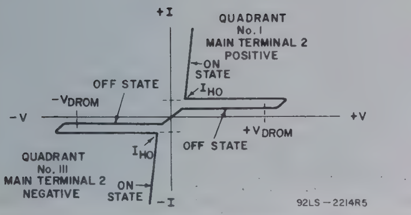

+I
QUADRANT
No. I
MAIN TERMINAL 2
POSITIVE
ON
STATE
I_{HO}
OFF STATE
$-V_{DROM}$
-V
+V
$+V_{DROM}$
OFF STATE
I_{HO}
QUADRANT
No. III
MAIN TERMINAL 2
NEGATIVE
ON
STATE
-I
92LS-2214R5

Fig. 1 – Principal voltage-current characteristic.

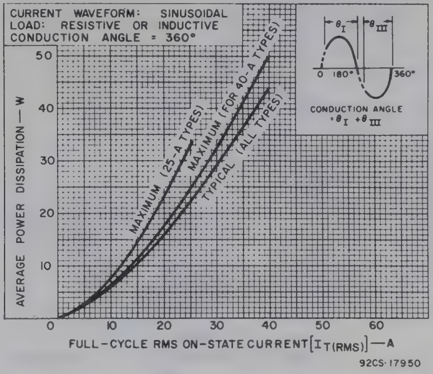


Fig. 2 – Power dissipation vs. on-state current.

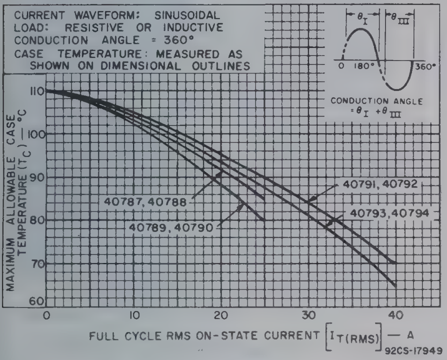


Fig. 3 – Maximum allowable case temperature vs. on-state current.

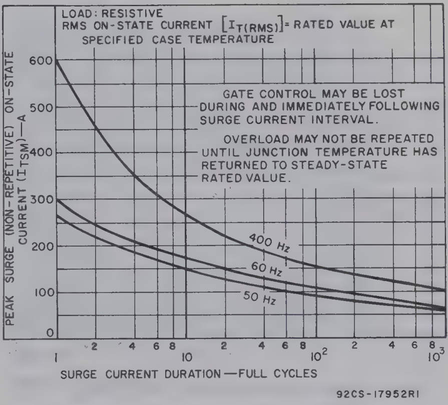


Fig. 4 – Peak surge on-state current vs. surge current duration.

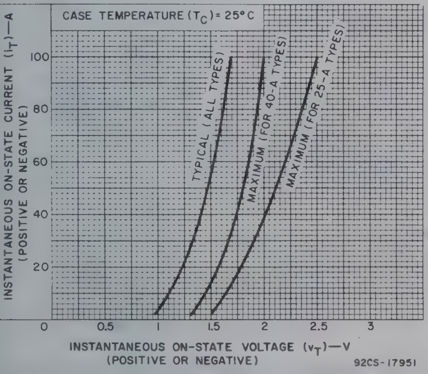


Fig. 5 – On-state current vs. on-state voltage.

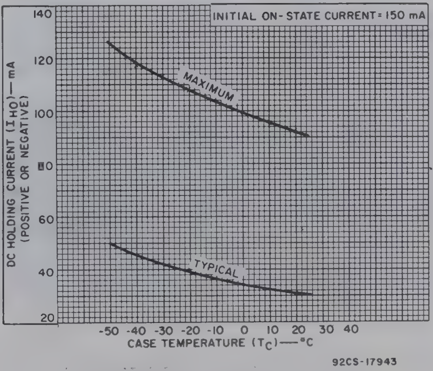


Fig. 6 – DC holding current vs. case temperature.

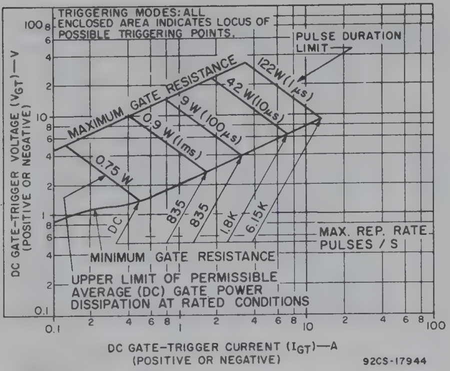


Fig. 7 — Gate-trigger characteristics and limiting conditions for determination of permissible gate-trigger pulses.

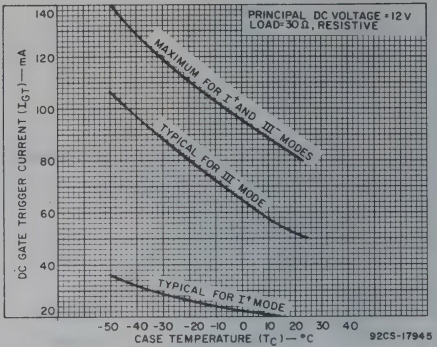


Fig. 8 — DC gate-trigger current vs. case temperature (I^+ & III^- modes

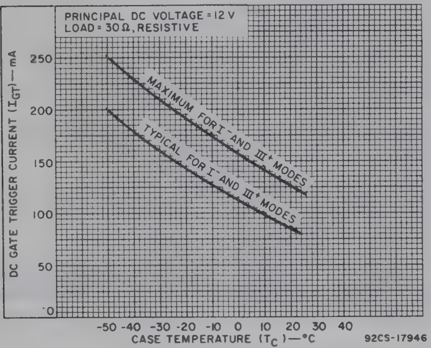


Fig. 9 — DC gate-trigger current vs. case temperature (I^- & III^+ modes).

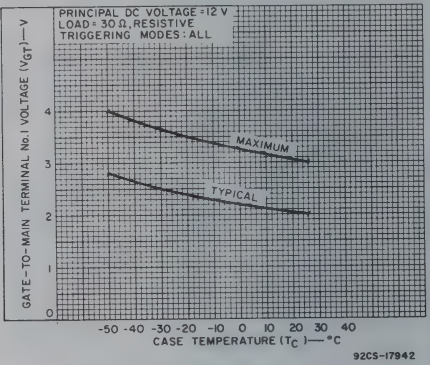


Fig. 10 — DC gate-trigger voltage vs. case temperature.

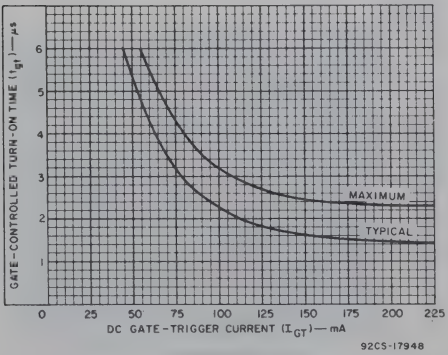


Fig. 11 — Turn-on time vs. gate trigger current.

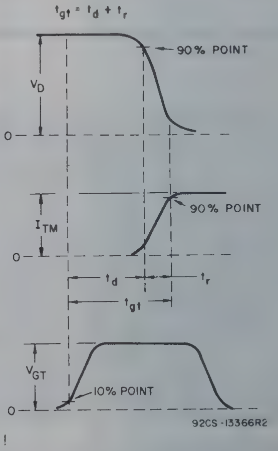

$t_{gt} = t_d + t_r$
90% POINT
V_D
0
I_{TM}
90% POINT
0
t_d
t_r
t_{gt}
V_{GT}
10% POINT
0
92CS-13366R2

Fig. 12 — Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).

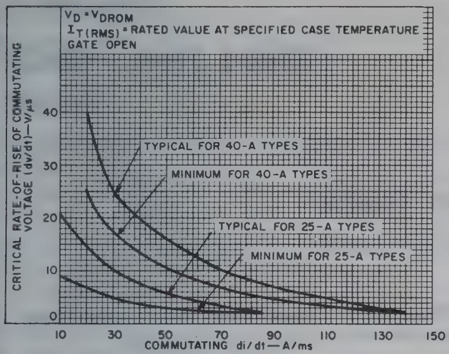


Fig. 13 – Commutating voltage vs. commutating current.

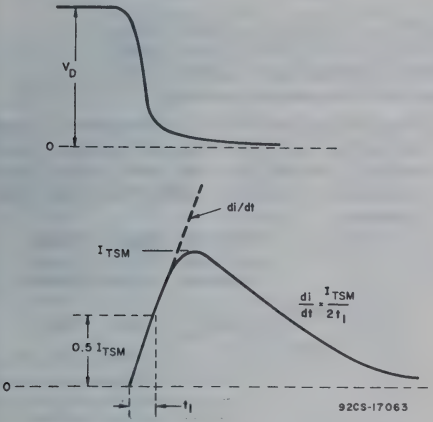
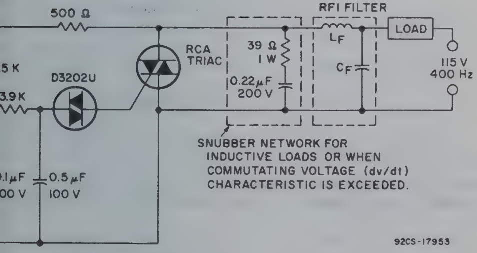

V_D
0
di/dt
I_{TSM}
$\frac{di}{dt} = \frac{I_{TSM}}{2t_1}$
0.5 I_{TSM}
0
t_1
92CS-17063

Fig. 15 – Rate of change of on-state current with time (defining di/dt).


500 Ω
5 K
D3202U
3.9 K
.1 µF
00 V
0.5 µF
100 V
RCA TRIAC
39 Ω
1 W
0.22 µF
200 V
RFI FILTER
L_F
C_F
LOAD
115 V
400 Hz
SNUBBER NETWORK FOR INDUCTIVE LOADS OR WHEN COMMUTATING VOLTAGE (dv/dt) CHARACTERISTIC IS EXCEEDED.
92CS-17953

g. 17 – Typical phase-control circuit for operation at 400 Hz.

TERMINAL CONNECTIONS

No.1—Gate
No.2—Main Terminal 1
Case, No.3—Main Terminal 2

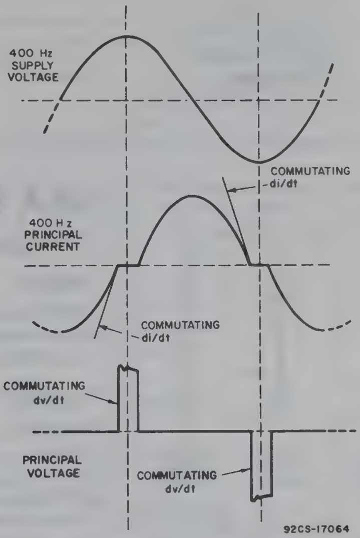

400 Hz SUPPLY VOLTAGE
COMMUTATING di/dt
400 Hz PRINCIPAL CURRENT
COMMUTATING di/dt
COMMUTATING dv/dt
PRINCIPAL VOLTAGE
COMMUTATING dv/dt
92CS-17064

Fig. 14 – Relationship between supply voltage and principal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

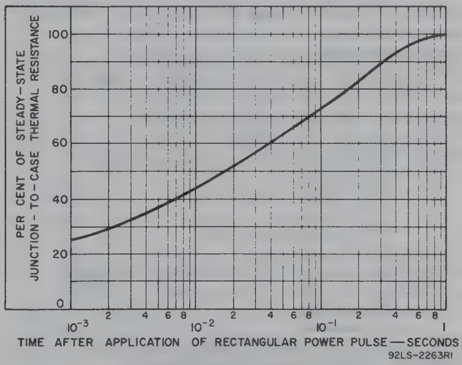


Fig. 16 – Transient junction-to-case thermal resistance vs. time.

WARNING:

The RCA isolated-stud package thyristors should be handled with care. The ceramic portion of these thyristors contains BERYLLIUM OXIDE as a major ingredient. Do not crush, grind, or abrade these portions of the thyristors because the dust resulting from such action may be hazardous if inhaled.

RCA
Solid State Division

Thyristors

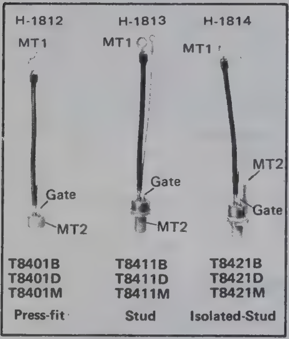
T8401 T8411 T8421 Series

60-A Silicon Triacs

For Phase-Control and Load-Switching Applications

Features:

- ■ di/dt Capability = 300 A/μs
- ■ Shorted-Emitter, Center-Gate Design
- ■ Low Switching Losses
- ■ Low On-State Voltage at High Current Le
- ■ Low Thermal Resistance



Voltage / Package	200 V	400 V	600 V
Press-fit	T8401B (41029)	T8401D (41030)	T8401M (41031)
Stud	T8411B (41032)	T8411D (41033)	T8411M (41034)
Iso-stud	T8421B (41035)	T8421D (41036)	T8421M (41037)

Numbers in parentheses (e.g. 41029) are former RCA type numbers

RCA T8401, T8411, and T8421 series triacs are gate-controlled, full-wave silicon ac switches. They are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative triggering voltages.

These triacs are intended for control of ac loads in applic tions such as heating controls motor controls, arc-weldi equipment, light dimmers, and power switching system They can also be used in air-conditioning and photocopyi equipment

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		T8401B T8411B T8421B	T8401D T8411D T8421D	T8401M T8421M T8421M	
REPETITIVE PEAK OFF-STATE VOLTAGE:●					
Gate open, T_J = −40 to 110°C	V_{DROM}	200	400	600	
RMS ON-STATE CURRENT (Conduction angle = 360°):	$I_{T(RMS)}$				
Case Temperature					
T_C = 85°C (Press-Fit types)			60		
80°C (Stud types)			60		
75°C (Isolated-Stud types)			60		
For other conditions			See Fig. 3		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}				
For one cycle of applied principal voltage, T_C as above					
60 Hz (sinusoidal)			600		
50 Hz (sinusoidal)			500		
For more than one cycle of applied principal voltage			See Fig. 4		
RATE OF CHANGE OF ON-STATE CURRENT:					
$V_{DM} = V_{DROM}$, I_{GT} = 300 mA, t_r = 0.1 μs (See Fig. 13)	di/dt		300		A
FUSING CURRENT (for Triac Protection):					
T_J = −40 to 110°C, t = 1.25 to 10 ms	I^2t		1800		A
PEAK GATE-TRIGGER CURRENT:■					
For 10 μs max. (See Fig. 7)	I_{GTM}		7		
GATE POWER DISSIPATION (See Fig. 7):					
Peak (For 10 μs max., $I_{GTM} \leqslant 7$ A (peak)	P_{GM}		42		
AVERAGE	$P_{G(AV)}$		0.75		
TEMPERATURE RANGE:▲					
Storage	T_{stg}		−40 to 150		
Operating (Case)	T_C		−40 to 110		
TERMINAL TEMPERATURE (During soldering):					
For 10 s max. (terminals and case)	T_T		225		
STUD TORQUE:	τ_s				
Recommended			125		in
Maximum (DO NOT EXCEED)			150		in

● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

■ For either polarity of gate voltage (V_G) with reference to main terminal 1. ▲ For temperature measurement reference point, see Dimensional O

CTRICAL CHARACTERISTICS *At Maximum Ratings Unless Otherwise Specified, and at Indicated Temperature*

CHARACTERISTIC	SYMBOL	LIMITS For All Types Except as Specified			UNITS
		MIN.	TYP.	MAX.	
k Off-State Current:●					
Gate open, V_{DROM} = Max. rated value	I_{DROM}	–	0.4	4	mA
ximum On-State Voltage:●					
For i_T = 100 A (peak), T_C = 25°C	v_{TM}	–	1.55	1.8	V
Holding Current:●					
Gate open, Initial principal current = 500 mA (dc)					
v_D = 12 V, T_C = 25°C	I_{HO}	–	20	60	
T_C = –40°C		–	–	85	mA
For other case temperatures		See Fig. 6			
tical Rate-of-Rise of Commutation Voltage:●					
For v_D = V_{DROM}, $I_{T(RMS)}$ = 60 A, commutating					
di/dt = 32 A/ms, gate unenergized, (See Fig. 14):	dv/dt				
T_C = 75°C (Press-fit types)		3	10	–	V/µs
= 65°C (Stud types)		3	10	–	
= 55°C (Isolated-stud types)		3	10	–	
tical Rate-of-Rise of Off-State Voltage:●					
For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 110°C:	dv/dt				V/µs
T8401B, T8411B, T8421B		50	200	–	
T8401D, T8411D, T8421D		30	150	–	
T8401M, T8411M, T8421M		20	100	–	
Gate-Trigger Current:●■ Mode V_{MT2} V_G					
For v_D = 12 V (dc) I+ positive positive	I_{GT}	–	20	75	mA
R_L = 30 Ω III− negative negative		–	40	75	
T_C = 25°C I− positive negative		–	40	150	
III+ negative positive		–	100	150	
Mode V_{MT2} V_G					
For v_D = 12 V (dc) I+ positive positive		–	35	150	
R_L = 30 Ω III− negative negative		–	80	150	
T_C = –40°C I− positive negative		–	100	400	
III+ negative positive		–	280	400	
For other case temperatures		See Figs. 8 & 9			
Gate-Trigger Voltage:●■					
For v_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C	V_{GT}	–	1.35	2.8	V
For other case temperatures		See Fig. 10			
e-Controlled Turn-On Time: (Delay Time + Rise Time)	t_{gt}				
For v_D = V_{DROM}, I_{GT} = 300 mA, t_r = 0.1 µs, i_T = 85 A (peak), T_C = 25°C (See Figs. 11 & 15)		–	1.2	2.5	µs
rmal Resistance, Junction-to-Case:					
Steady-State					
Press-fit types	$R_{\theta JC}$	–	–	0.3	°C/W
Stud types		–	–	0.35	
Isolated-stud types		–	–	0.4	
Transient (Press-fit & Stud types)		See Fig. 12			

For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
For either polarity of gate voltage (V_G) with reference to main terminal 1.

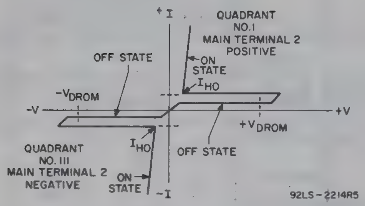

+I
QUADRANT NO.1
MAIN TERMINAL 2 POSITIVE
ON STATE
I_HO
OFF STATE
-V_DROM
-V
+V
+V_DROM
QUADRANT NO. III
MAIN TERMINAL 2 NEGATIVE
I_HO
OFF STATE
ON STATE
-I
92LS-2214R5

Fig. 1 — Principal voltage-current characteristic.

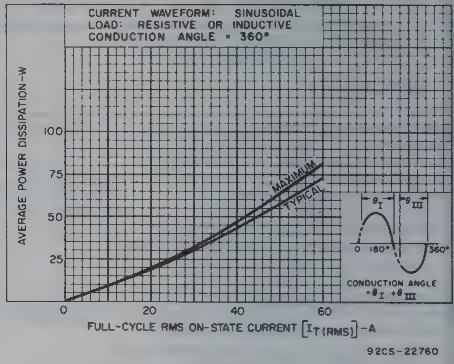


Fig. 2 — Power dissipation vs. on-state current.

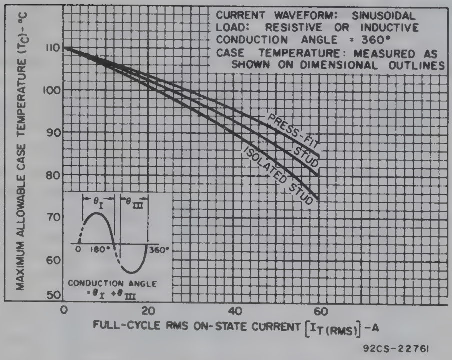


Fig. 3 — Maximum allowable case temperature vs. on-state current.

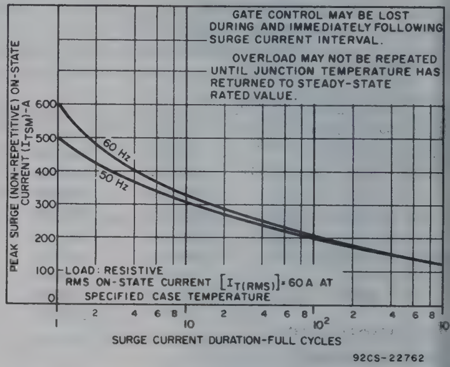


Fig. 4 — Peak surge on-state current vs. surge current duration.

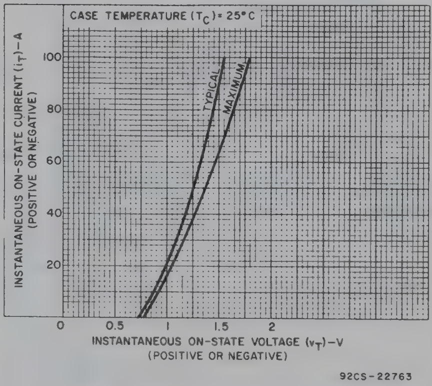


Fig. 5 — On-state current vs. on-state voltage.

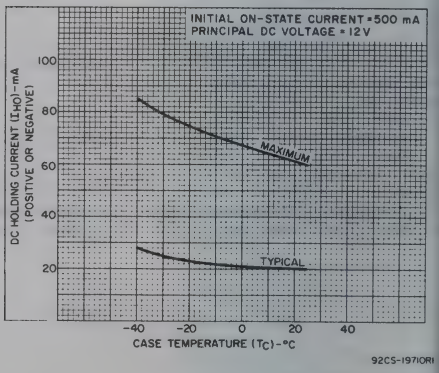


Fig. 6 — DC holding current vs. case temperature.

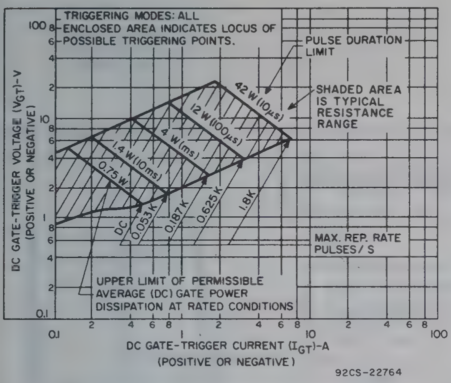


Fig. 7 — Gate-trigger characteristic and limiting conditions for determination of permissible gate-trigger pulses.

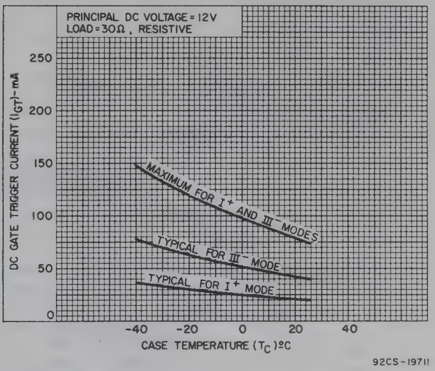


Fig. 8 — DC gate-trigger current vs. case temperature (I^+ and III^- modes).

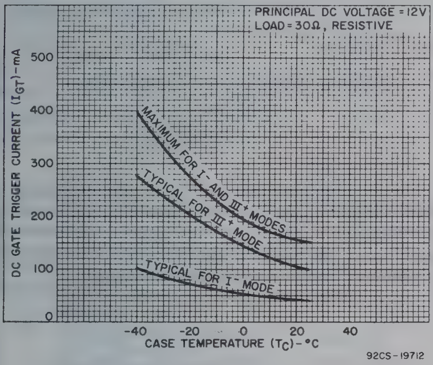


Fig. 9 — DC gate-trigger current vs. case temperature (I^- and III^+ modes).

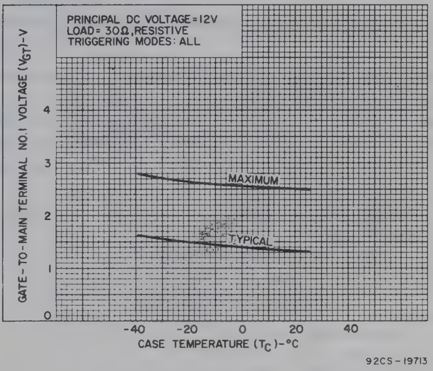


Fig. 10 — DC gate-trigger voltage vs. case temperature.

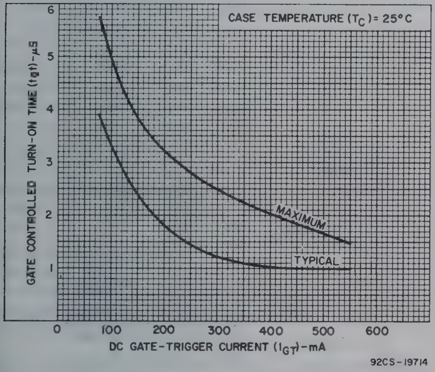


Fig. 11 — Turn on time vs. gate-trigger current.

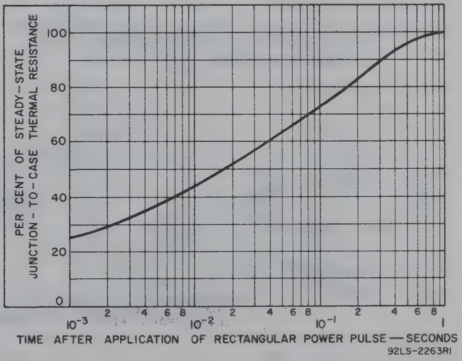


Fig. 12 — Transient junction-to-case thermal resistance vs. time.

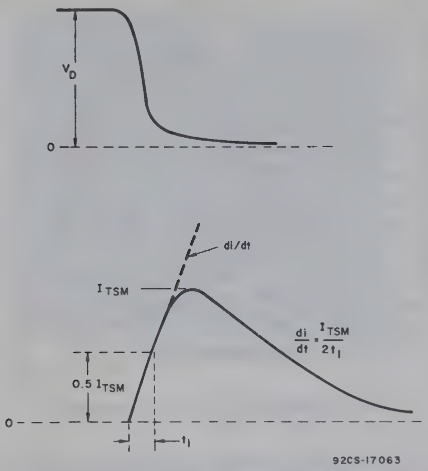


Fig. 13 — Rate-of-change of on-state current with time (defining di/dt).

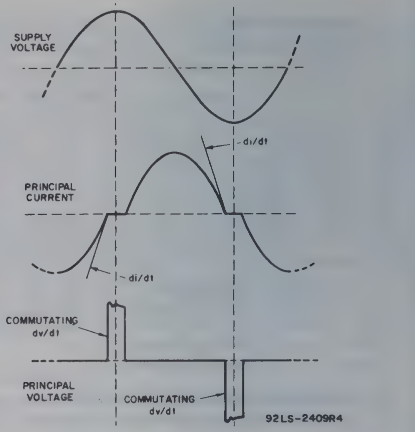


Fig. 14 — Relationship between supply voltage and principal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

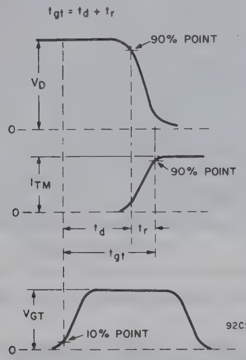
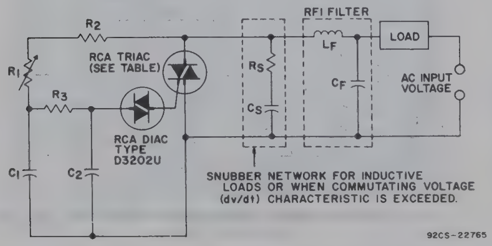


Fig. 15 — Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).



RFI FILTER
R_2
LOAD
L_F
R_1
RCA TRIAC (SEE TABLE)
R_S
C_F
AC INPUT VOLTAGE
R_3
C_S
RCA DIAC TYPE D3202U
C_1
C_2
SNUBBER NETWORK FOR INDUCTIVE LOADS OR WHEN COMMUTATING VOLTAGE (dv/dt) CHARACTERISTIC IS EXCEEDED.
92CS-22765

Fig. 16 — Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.

TERMINAL CONNECTIONS FOR ALL TYPES

No. 1 — Gate
No. 2 — Main Terminal 1
Case, No. 3 — Main Terminal 2

WARNING: The ceramic of the isolated stud package contains beryllium oxide. Do not crush, grind, or abrade this part because the dust resulting from such action may be hazardous if inhaled, Disposal should be by burial.

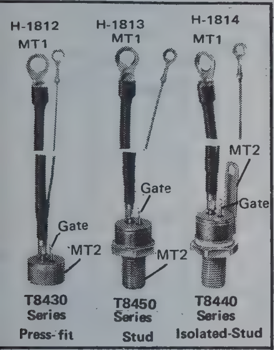
AC INPUT VOLTAGE		120 V 60 Hz	240 V 60 Hz	240 V 50 Hz
C_1		0.1 µF 200 V	0.1 µF 400 V	0.1 µF 400 V
C_2		0.1 µF 100 V	0.1 µF 100 V	0.1 µF 100 V
R_1		100 kΩ ½ W	200 kΩ ½ W	250 kΩ ½ W
R_2		2.2KΩ 1/2W	3.3KΩ 1/2W	3.3KΩ 1/2W
R_3		15 kΩ ½ W	15 kΩ ½ W	15 kΩ ½ W
SNUBBER NETWORK FOR 60 A (RMS)• INDUCTIVE LOAD	C_S	0.18 0.22 µF 200 V	0.18 0.22 µF 400 V	0.18 0.22 µF 400 V
	R_S	330 390 Ω ½ W	330 390 Ω ½ W	330 390 Ω ½ W
RFI FILTER	C_F•	0.1 µF 200 V	0.1 µF 400 V	0.1 µF 400 V
	L_F•	100 µH	200 µH	200 µH
RCA TRIACS		T8401B T8411B T8421B	T8401D T8411D T8421D	T8401D T8411D T8421D

• For other RMS Current values refer to RCA Application Note AN-4745.

• Typical values for Lamp dimming circuits.

RCA
Solid State
Division

T8430 T8440 T8450 Series



80-A Silicon Triacs

Press-Fit, Stud, and Isolated-Stud Packages

Features:

- di/dt Capability = 300 A/μs
- Shorted-Emitter Center-Gate Design
- Low Switching Losses
- Low On-State Voltage at High Current Levels
- Low Thermal Resistance

Package \ Voltage	200 V Types	400 V Types	600 V Types
Press-fit	T8430B (40916)	T8430D (40917)	T8430M (40918)
Stud	T8440B (40919)	T8440D (40920)	T8440M (40921)
Isolated-stud	T8450B (40922)	T8450D (40923)	T8450M (40924)

Numbers in parentheses are former RCA type numbers.

hese RCA triacs are gate-controlled full-wave silicon ac witches. They are designed to switch from an off-state to an n-state for either polarity of applied voltage with positive or egative gate triggering voltages.

These triacs are intended for control of ac loads in applications such as heating controls, motor controls, arc-welding equipment, light dimmers, and power switching systems. They can also be used in air-conditioning and photocopying equipment.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		T8430B T8440B T8450B	T8430D T8440D T8450D	T8430M T8440M T8450M	
REPETITIVE PEAK OFF-STATE VOLTAGE:* Gate open, T_J = –40 to 110°C	V_{DROM}	200	400	600	V
RMS ON-STATE CURRENT (Conduction Angle = 360°): Case temperature	$I_{T(RMS)}$				
T_C = 75°C (Press-Fit types)		80			A
65°C (Stud types)		80			A
55°C (Isolated-Stud types)		80			A
For other conditions		See Fig. 3			
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT: For one cycle of applied principal voltage, T_C as above	I_{TSM}				
60 Hz (sinusoidal)		850			A
50 Hz (sinusoidal)		720			A
For more than one cycle of applied principal voltage		See Fig. 4			
RATE-OF-CHANGE OF ON-STATE CURRENT: $V_{DM} = V_{DROM}$, I_{GT} = 300 mA, t_r = 0.1μs *(See Fig. 13)*	di/dt	300			A/μs
FUSING CURRENT (for Triac Protection): T_J = –40 to 110°C, t = 1.25 to 10 ms	I^2t	3600			A^2s
PEAK GATE-TRIGGER CURRENT: ■ For 10μs max. *(See Fig. 7)*	I_{GTM}	7			A
GATE POWER DISSIPATION: Peak (For 10μs max., $I_{GTM} \leq$ 7A (peak), *(See Fig. 7)*	P_{GM}	40			W
Average	$P_{G(AV)}$	0.75			W
TEMPERATURE RANGE:▲ Storage	T_{stg}	-40 to 150			°C
Operating (Case)	T_C	-40 to 110			°C
TERMINAL TEMPERATURE (During soldering): For 10 s max. (terminals and case)	T_T	225			°C

---

ormerly RCA Dev. Nos. TA7752–TA7757, and TA7937–TA7939, respectively.
For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
For either polarity of gate voltage (V_G) with reference to main terminal 1.
For temperature measurement reference point, see Dimensional Outline.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load. (Cont'd.).

		T8430B T8440B T8450B	T8430D T8440D T8450D	T8430M T8440M T8450M
STUD TORQUE:	τ_s			
Recommended			125	in.-lb
Maximum (DO NOT EXCEED)			150	in.-lb

ELECTRICAL CHARACTERISTICS at Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS MIN.	LIMITS TYP.	LIMITS MAX.	UNITS
Peak Off-State Current:♠ Gate open, T_J = 110°C, V_{DROM} = Max. rated value	I_{DROM}	–	0.4	4	mA
Maximum On-State Voltage:♠ For i_T = 200 A (peak), T_C = 25°C	V_{TM}	–	1.7	2	V
DC Holding Current:♠ Gate open, Initial principal current = 500 mA (dc), v_D = 12V:					
T_C = 25°C	I_{HO}	–	20	60	mA
= -40°C		–	–	85	
For other case temperatures			See *Fig. 6*		
Critical Rate-of-Rise of Commutation Voltage:♠ For v_D = V_{DROM}, $I_{T(RMS)}$ = 80 A, commutating di/dt = 42 A/ms, gate unenergized, (See *Fig. 14*):					
T_C = 75°C (Press-fit types)		3	10	–	
= 65°C (Stud types)	dv/dt	3	10	–	V/µs
= 55°C (Isolated-stud types)		3	10	–	
Critical Rate-of-Rise of Off-State Voltage:♠ For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 110°C:					
T8430B, T8440B, T8450B		50	200	–	
T8430D, T8440D, T8450D	dv/dt	30	150	–	V/µs
T8430M, T8440M, T8450M		20	100	–	
DC Gate-Trigger Current:♠♦ Mode / V_{MT2} / V_G					
For v_D = 12 V (dc) I+ positive positive		–	20	75	
R_L = 30 Ω III- negative negative		–	40	75	
T_C = 25°C I- positive negative		–	40	150	
III+ negative positive	I_{GT}	–	100	150	mA
Mode / V_{MT2} / V_G					
For v_D = 12 V (dc) I+ positive positive		–	35	150	
R_L = 30Ω III- negative negative		–	80	150	
T_C = -40°C I- positive negative		–	100	400	
III+ negative positive		–	280	400	
For other case temperatures			See *Figs. 8 & 9*		
DC Gate-Trigger Voltage:♠♦ For v_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C	V_{GT}	–	1.35	2.5	V
For other case temperatures			See *Fig. 10*		
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For v_D = V_{DROM}, I_{GT} = 300 mA, t_r = 0.1 µs, i_T = 112 A (peak), T_C = 25°C (See *Figs. 11 & 15*)	t_{gt}	–	1.2	2.5	µs
Thermal Resistance, Junction-to-Case: Steady-State					
Press-fit types		–	–	0.3	
Stud types	$R_{\theta JC}$	–	–	0.35	°C/W
Isolated-stud types		–	–	0.4	
Transient (Press-fit & Stud types)			See *Fig. 12*		

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
♦ For either polarity of gate voltage (V_G) with reference to main terminal 1.

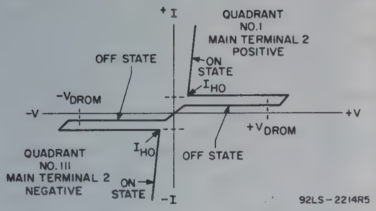

+I
QUADRANT
NO.I
MAIN TERMINAL 2
POSITIVE
OFF STATE
ON
STATE
I_{HO}
$-V_{DROM}$
-V
+V
$+V_{DROM}$
QUADRANT
NO. III
MAIN TERMINAL 2
NEGATIVE
I_{HO}
OFF STATE
ON
STATE
-I
92LS-2214R5

Fig. 1 — Principal voltage-current characteristic.

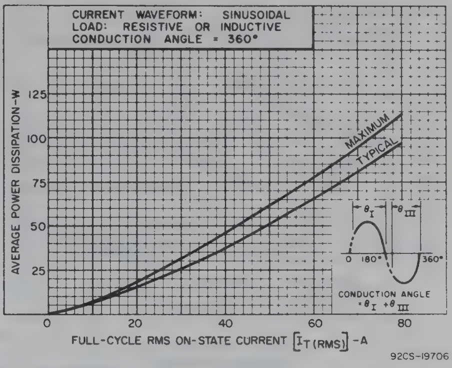


Fig. 2 — Power dissipation vs. on-state current.

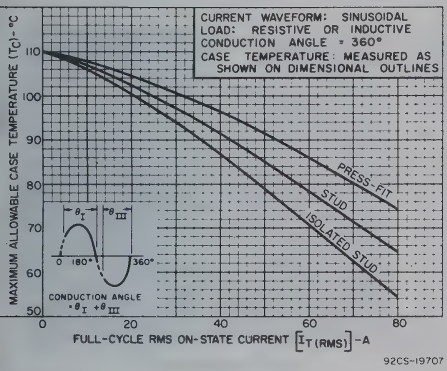


Fig. 3 — Maximum allowable case temperature vs. on-state current.

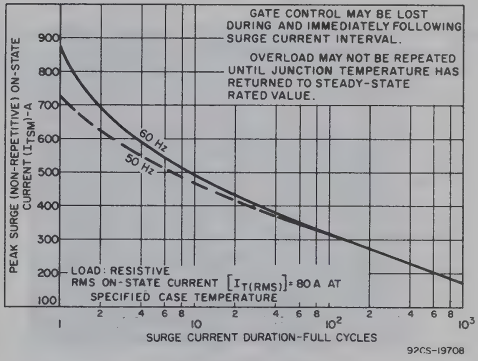


Fig. 4 — Peak surge on-state current vs. surge current duration.

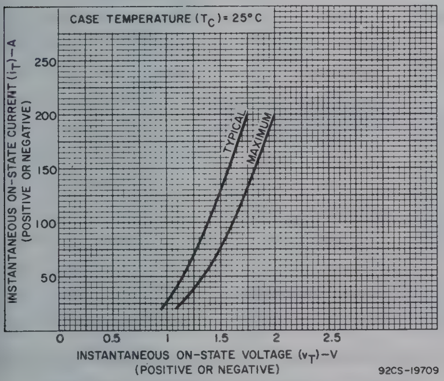


Fig. 5 — On-state current vs. on-state voltage.

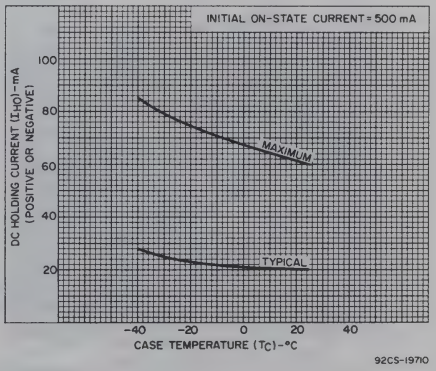


Fig. 6 — DC holding current vs. case temperature.

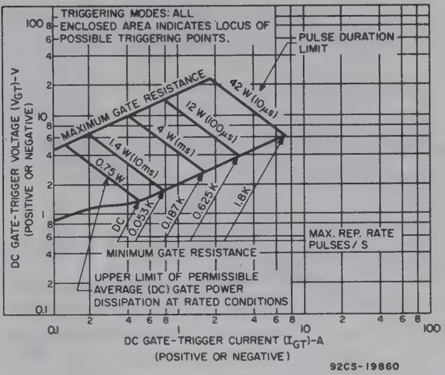


Fig. 7 – Gate-trigger characteristics and limiting conditions for determination of permissible gate-trigger pulses.

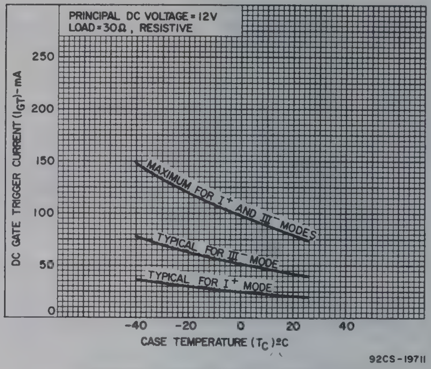


Fig. 8 – DC gate-trigger current vs. case temperature (I^+ & III^- modes).

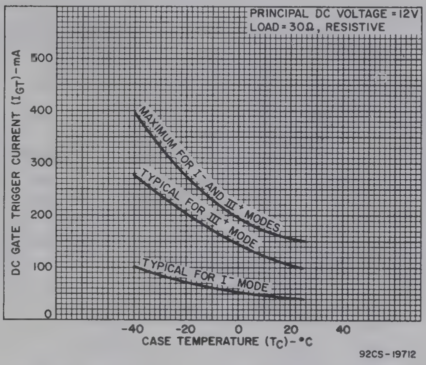


Fig. 9 – DC gate-trigger current vs. case temperature (I^- & III^+ modes).

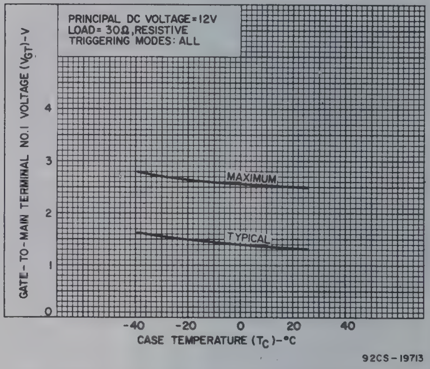


Fig. 10 – DC gate-trigger voltage vs. case temperature.

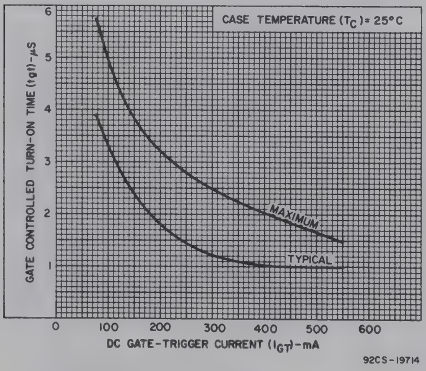


Fig. 11 – Turn-on time vs. gate-trigger current.

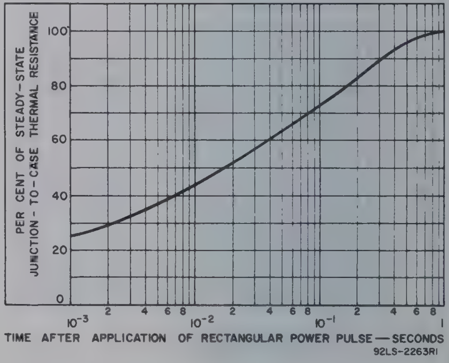
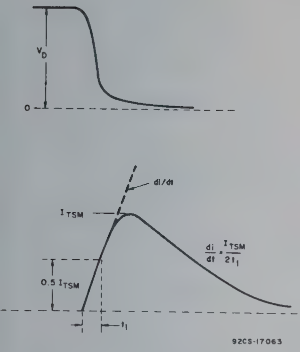


Fig. 12 – Transient junction-to-case thermal resistance vs. time.



ig. 13 – Rate-of-change of on-state current with time (defining di/dt).

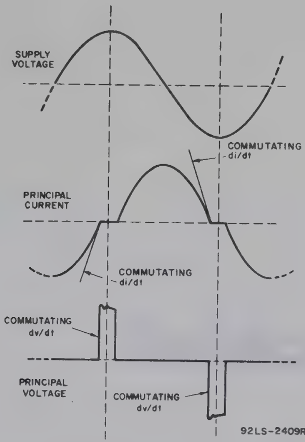


Fig. 14–Relationship between supply voltage and prinicpal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

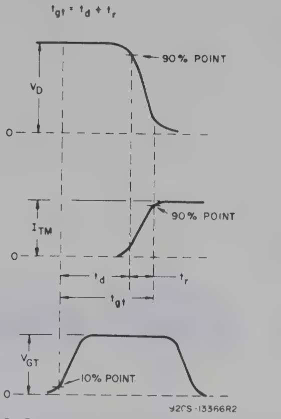
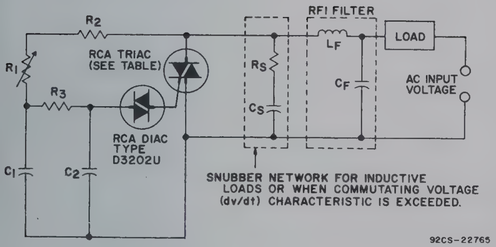


Fig. 15–Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).


R2
R1
RCA TRIAC (SEE TABLE)
R3
RCA DIAC TYPE D3202U
C1
C2
RS
CS
RFI FILTER
LF
CF
LOAD
AC INPUT VOLTAGE
SNUBBER NETWORK FOR INDUCTIVE LOADS OR WHEN COMMUTATING VOLTAGE (dv/dt) CHARACTERISTIC IS EXCEEDED.
92CS-22765

AC INPUT VOLTAGE		120 V 60 Hz	240 V 60 Hz	240 V 50 Hz
C_1		0.1 µF 200 V	0.1 µF 400 V	0.1 µF 400 V
C_2		0.1 µF 100 V	0.1 µF 100 V	0.1 µF 100 V
R_1		100 kΩ ½ W	200 kΩ ½ W	250 kΩ ½ W
R_2		2.2 kΩ ½ W	3.3 kΩ ½ W	3.3 kΩ ½ W
R_3		15 kΩ ½ W	15 kΩ ½ W	15 kΩ ½ W
SNUBBER NETWORK FOR 80 A (RMS)● INDUCTIVE LOAD	C_S	0.18 0.22 µF 200 V	0.18 0.22 µF 400 V	0.18 0.22 µF 400 V
	R_S	330 390 Ω ½ W	330 390 Ω ½ W	330 390 Ω ½ W
RFI FILTER	C_F●	0.1 µF 200 V	0.1 µF 400 V	0.1 µF 400 V
	L_F●	100 µH	200 µH	200 µH
RCA TRIACS		T8430B T8440B T8450B	T8430D T8440D T8450D	T8430D T8440D T8450D

● For other RMS Current values refer to RCA Application Note AN-4745.

● Typical values for Lamp dimming circuits.

Fig. 16 – Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.

TERMINAL CONNECTIONS FOR ALL TYPES

No. 1 – Gate
No. 2 – Main Terminal 1
Case, No. 3 – Main Terminal 2

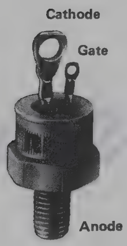
WARNING: The ceramic of the isolated stud package contains beryllium oxide. Do not crush, grind, or abrade this part because the dust resulting from such action may be hazardous if inhaled. Disposal should be by burial.

Technical Data-SCR's

RCA
Solid State Division

Thyristors
2N681-2N690

All-Diffused Types for Power-Control and Power-Switching Applications



JEDEC TO-48

H-1601

RCA-2N681 through 2N690 controlled-rectifiers are all-diffused, three-junction, silicon devices for use in power-control and power-switching applications requiring blocking-voltage capabilities to 600 volts and forward-current capability of 16 amperes (average value) or 25 amperes (rms value).

FEATURES

- All-diffused construction – assures exceptional uniformity and stability of characteristics
- Multi-diffusion process – permits precise control of individual junction parameters
- Symmetrical gate-cathode construction – provides uniform current density, rapid electrical conduction, and efficient heat dissipation
- Direct-soldered internal construction – assures exceptional resistance to fatigue
- Each unit aged at maximum ratings to assure dependable performance
- All-welded construction and hermetic sealing
- Shorted emitter gate-cathode construction
- Low leakage currents, both forward and reverse
- Low forward voltage drop at high current levels
- Low thermal resistance
- Exceptionally high stud-torque capability through use of high-strength copper-alloy stud

Absolute-Maximum Ratings, for Operation with Sinusoidal AC Supply Voltage at a Frequency between 50 and 400 Hz and with Resistive or Inductive Load

RATINGS	2N681	2N682	2N683	2N684	2N685	2N686	2N687	2N688	2N689	2N690	UNITS
Transient Peak Reverse Voltage (Non-Repetitive), v_{RM} (non-rep)	35	75	150	225	300	350	400	500	600	720	V
Peak Reverse Voltage (Repetitive), v_{RM} (rep)	25	50	100	150	200	250	300	400	500	600	V
Peak Forward Blocking Voltage (Repetitive), v_{FBOM} (rep)	600										V
Forward Current:											
For case temperature (T_C) of +65°C, and a conduction angle of 180°, I_{FAV}	16										A
RMS value, I_{FRMS}	25										A
For other case temperatures and conduction angles	*See Fig. 2*										
Peak Surge Current, i_{FM} (surge)											
For one cycle of applied voltage, T_C = 65°C	150										A
For more than one cycle of applied voltage	*See Fig. 3*										
Rate of Change of Forward Current: $V_D = V_{DROM}$, I_{GT} = 200 mA, tr = 0.5 μs (See Fig. 7), di/dt	200										A/μs
Fusing Current (for SCR Protection): T_j = –65 to 125°C, t = 1 to 8.3 ms, I^2t	50										A^2s
Peak Gate Power, P_{GM}	5										W

Absolute-Maximum Ratings, for Operation with Sinusoidal AC Supply Voltage at a Frequency between 50 and 400 Hz and with Resistive or Inductive Load (Cont'd.).

RATINGS	2N681	2N682	2N683	2N684	2N685	2N686	2N687	2N688	2N689	2N690	UNITS
erage Forward Gate Power, P_{GAV}	0.5										W
ak Forward Gate Current, i_{GKM}	2										A
ak Gate Voltage:											
Forward, v_{GKM}	10										V
Reverse, v_{KGM}	5										V
mperature:											
Storage, T_{stg}	–65 to +150										oC
Operating, Case#, T_C	–65 to +125										oC
Free Air, T_{FA}	*See Fig. 4*										
ud Torque:, τ_s											
Recommended	35										in-1b
Maximum (DO NOT EXCEED)	50										in-1b

Electrical and Thermal Characteristics at Maximum Electrical Ratings (unless otherwise specified), and at Indicated Case Temperature, T_C.

CHARACTERISTICS	2N681	2N682	2N683	2N684	2N685	2N686	2N687	2N688	2N689	2N690	UNITS
nimum Forward Breakover Voltage, V_{BOO}:											
At T_C = +125oC	25	50	100	150	200	250	300	400	500	600	V
ximum Average (DC) Forward Blocking Current, I_{FBOAV}:											
At T_C = +125oC	6.5	6.5	6.5	6.5	6	5.5	5	4	3	2.5	mA
ximum Average (DC) Reverse Blocking Current, I_{RBOAV}:											
At T_C = +125oC	6.5	6.5	6.5	6.5	6	5.5	5	4	3	2.5	mA
ximum Average Forward Voltage Drop, V_{FAV}:											
At a Forward Current of 25 mperes and a T_C = +65oC	0.86										V
ximum DC Gate-Trigger Current, I_{GT}:											
At T_C = +125oC	25										mA
Gate-Trigger Voltage, V_{GT}:											
Maximum at T_C = –65o to +125oC	3										V
Minimum at T_C = +125oC	0.25										V
lding Current, i_{HOO}:											
Typical at T_C = +125oC	15										mA
ximum Thermal Resistance unction-to-Case, $\theta_{J\text{-}C}$	2										oC/W

For temperature measurement reference point, see Dimensional Outline.

TYPICAL E-I CHARACTERISTIC OF SILICON CONTROLLED-RECTIFIER

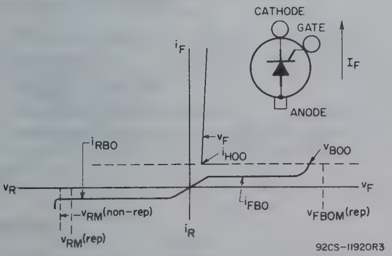
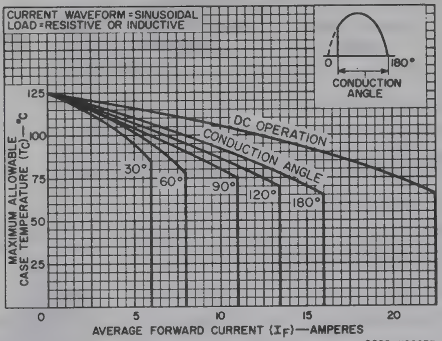


Fig. 1

TERMINAL CONNECTIONS

No. 1–Gate
No. 2–Cathode
Case, No. 3–Anode

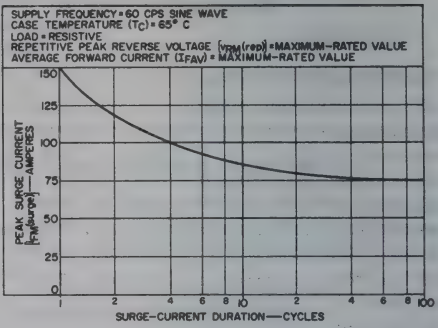
RATING CHART



92CS-11928R3

Fig.2

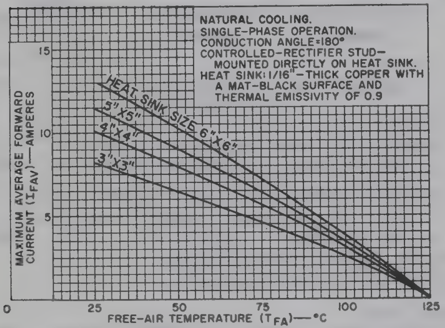
SURGE CURRENT RATING CHART



92CS-11918R1

Fig.3

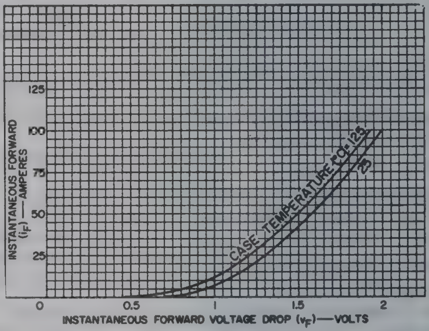
OPERATION GUIDANCE CHART



92CS-11916R1

Fig.4

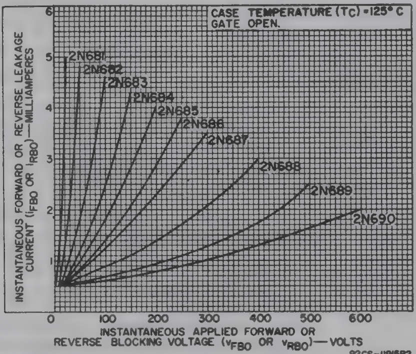
FORWARD CHARACTERISTICS



92CS-11917

Fig.5

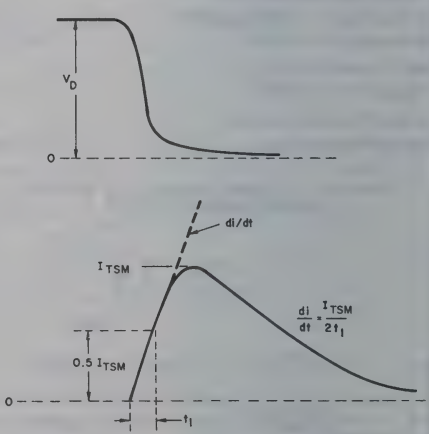
FORWARD AND REVERSE LEAKAGE CHARACTERISTICS



92CS-11915R2

Fig.6

di/dt CHARACTERISTIC


VD
0
di/dt
ITSM
di/dt = ITSM/2t1
0.5 ITSM
0
t1

92CS-17063

Fig. 7

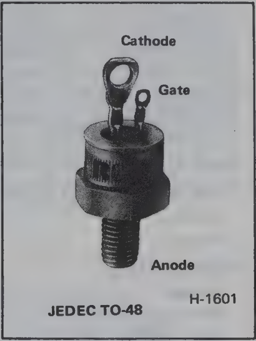
RCA
Solid State Division

Thyristors

2N1842A 2N1845A 2N1848A
2N1843A 2N1846A 2N1849A
2N1844A 2N1847A 2N1850A

RCA—2N1842A-2N1850A controlled-rectifiers are all-diffused, three-junction silicon devices for use in power-control and power-switching applications requiring blocking-voltage capabilities to 500 volts and forward-current capability of 10 amperes (average value) or 16 amperes (rms value).

All-Diffused Types for Power-Control and Power-Switching Applications



FEATURES—

- all-diffused construction—assures exceptional uniformity and stability of characteristics
- multi-diffusion process—permits precise control of individual junction parameters
- direct-soldered internal construction—assures exceptional resistance to fatigue
- shorted emitter gate-cathode construction
- each unit aged at maximum ratings to assure dependable performance
- symmetrical gate-cathode construction—provides uniform current density, rapid electrical conduction, and efficient heat dissipation
- designed to meet stringent military environmental and mechanical specifications
- exceptionally rugged terminals
- hermetic seals
- low leakage currents, both forward and reverse
- welded construction
- low forward voltage drop at high current levels
- low thermal resistance
- exceptionally high stud-torque capability through use of high-strength copper-alloy stud

bsolute-Maximum Ratings, for Operation with Sinusoidal AC Supply Voltage a Frequency between 50 and 400 Hz, and with Resistive or Inductive Load

RATINGS	2N1842A	2N1843A	2N1844A	2N1845A	2N1846A	2N1847A	2N1848A	2N1849A	2N1850A	UNITS
TRANSIENT PEAK REVERSE VOLTAGE NON-REPETITIVE)	35	75	150	225	300	350	400	500	600	volts
PEAK REVERSE VOLTAGE (REPETITIVE)	25	50	100	150	200	250	300	400	500	volts
PEAK FORWARD BLOCKING VOLTAGE (REPETITIVE)	← 600 →									volts
AVERAGE FORWARD CURRENT: For a case temperature# of +80°C and a conduction angle of 180°	← 10 →									amp
For other case temperatures and conduction angles	← *See Fig. 2* →									
PEAK SURGE CURRENT: For one cycle of applied voltage	← 125 →									amp
For more than one cycle of applied voltage	← *See Fig. 3* →									

Absolute-Maximum Ratings, for Operation with Sinusoidal AC Supply Voltage at a Frequency between 50 and 400 Hz, and with Resistive or Inductive Load (Cont'd.)

RATINGS	2N1842A 2N1844A 2N1843A	2N1845A 2N1847A 2N1846A	2N1848A 2N1850A 2N1849A	UNITS
RATE OF CHANGE OF FORWARD CURRENT: $V_D = V_{DROM}$, I_{GT} = 200 mA, $t_r = 0.1$ µs *(See Fig. 9)*	200			amp/µs
FUSING CURRENT (for SCR protection): T_J = –65 to 125°C, t = 1 to 8.3 ms	40			amp^{2}s
PEAK GATE POWER	5			watts
AVERAGE GATE POWER	0.5			watt
PEAK FORWARD GATE CURRENT	2			amp
PEAK FORWARD GATE VOLTAGE:				
Forward	10			volts
Reverse	5			volts
TEMPERATURE:				
Storage	–65 to +125			°C
Operating (Case)#	–65 to +125			°C
Operating (Free-air)	*See Fig. 4*			
STUD TORQUE:				
Recommended	35			in-16
Maximum (Do not exceed)	50			in-16

#Measured at the center of any of the six major faces on the perimeter of the hexagonal flange.

Electrical and Thermal Characteristics at Maximum Electrical Ratings (unless otherwise specified), and at Indicated Case Temperature, T_C

CHARACTERISTICS	T_C °C	2N1842A 2N1844A 2N1843A			2N1845A 2N1847A 2N1846A			2N1848A 2N1850A 2N1849A			UNITS
Minimum Forward Breakover Voltage	+125	25	50	100	150	200	250	300	400	500	volts
Maximum Average Forward Blocking Current	+125	22.5	19	12.5	6.5	6	5.5	5	4	3	ma
Maximum Average Reverse Blocking Current	+125	22.5	19	12.5	6.5	6	5.5	5	4	3	ma
Maximum Average Forward Voltage Drop	+80	1.2									volts
Maximum DC Gate Trigger Current	+125	45									ma
DC Gate-Trigger Voltage:											
Maximum	–40	3.5									volts
	–65	3.7									volts
Minimum	+125	0.25									volt
	+100	0.3									volt
Holding Current (Typical)	+125	8									ma
Maximum Thermal Resistance, Junction-to-Case	–	2									°C/wa

#Measured at the center of any of the six major faces on the perimeter of the hexagonal flange.

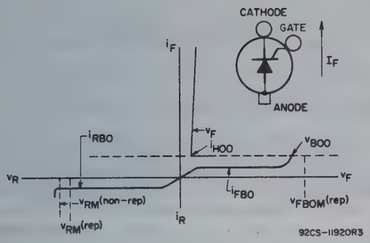

CATHODE
GATE
I_F
ANODE
i_F
i_{RBO}
v_F
i_{HOO}
v_{BOO}
v_R
v_F
i_{FBO}
v_{RM}(non-rep)
v_{RM}(rep)
i_R
v_{FBOM}(rep)
92CS-11920R3

Fig. 1 - Typical E-I Characteristic of Silicon Controlled-Rectifier.

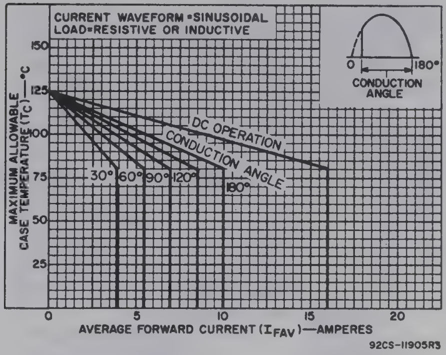
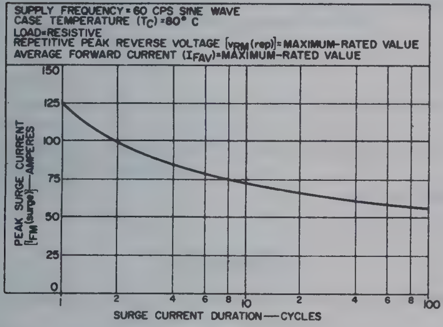
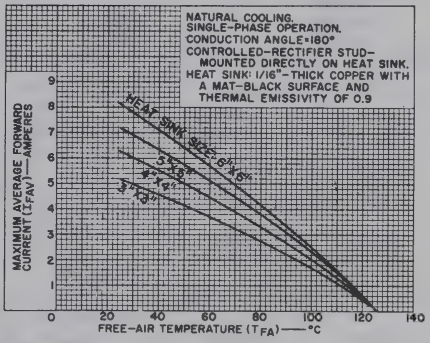


Fig. 2 - Rating Chart for Types 2N1842A through 2N1850A.



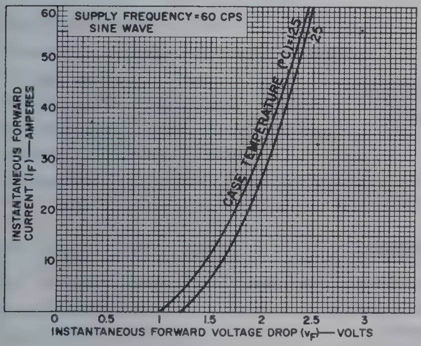
92CS-11904R1

Fig. 3 - Surge Current Rating Chart for Types 2N1842A through 2N1850A.



92CS-11907R1

Fig. 4 - Operation Guidance Chart for Types 2N1842A through 2N1850A.



92CS-11912R1

Fig. 5 - Maximum Forward Characteristics for Types 2N1842A through 2N1850A.

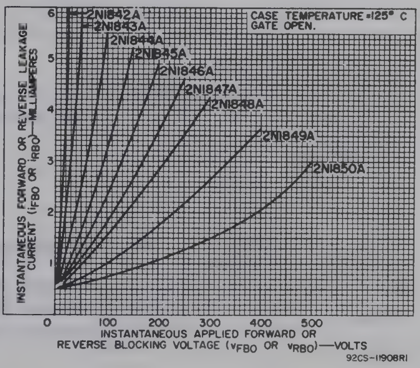


Fig. 6 - Typical Forward and Reverse Leakage Characteristics for Types 2N1842A through 2N1850A.

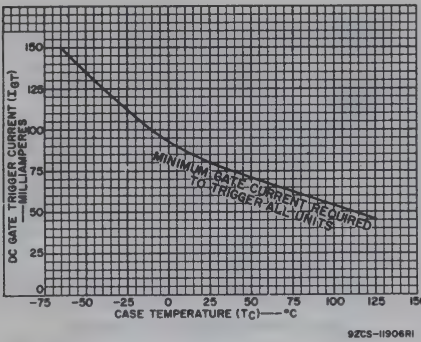


Fig. 7 - Gate Trigger-Current Characteristic for Types 2N1842A through 2N1850A.

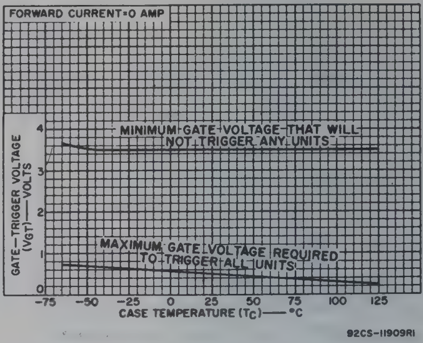


Fig. 8 - Gate Trigger-Voltage Characteristics for Types 2N1842A through 2N1850A.

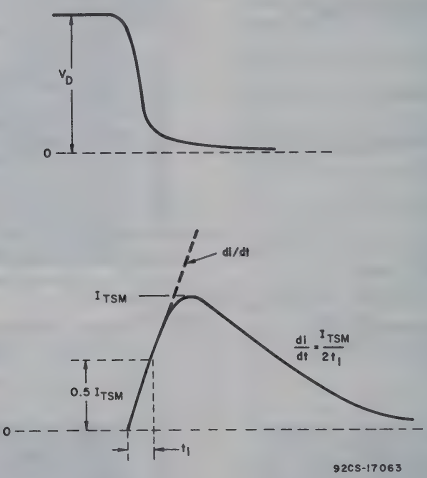

V_D
0
di/dt
I_{TSM}
$\frac{di}{dt} = \frac{I_{TSM}}{2t_1}$
0.5 I_{TSM}
0
t_1
92CS-17063

Fig. 9 – Rate of change of on-state current with time (defining di/dt).

TERMINAL CONNECTIONS

Terminal 1 (Small Lug) — Gate
Terminal 2 (Large Lug) — Cathode
Terminal 3 (Stud) — Anode

Solid State
Division

Thyristors

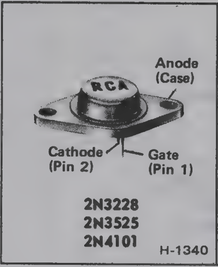
2N3228 2N3529
2N3525 2N4101
2N3528 2N4102

All-Diffused SCR's for Low-Cost Power-Control and Power-Switching Applications

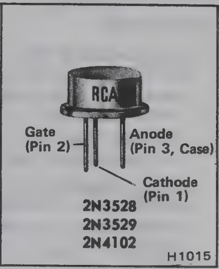
RCA 2N3228*, 2N3525*, 2N4101*, and 2N3528●, 2N3529●, and 2N4102● are all-diffused, three-junction, silicon controlled-rectifiers (SCR's▲) intended for use in power-control and power-switching applications.

Types 2N3228, 2N3525, and 2N4101 use the JEDEC TO-66 package and have a blocking voltage capability of up to 600 volts and a forward current rating of 5 amperes rms value) at a case temperature of 75°C.

Types 2N3528, 2N3529, and 2N4102 use the JEDEC TO-8 package and have a blocking voltage capability of up to 600 volts and a forward current rating of 2 amperes rms value) at an ambient temperature of 25°C.



JEDEC TO-66



JEDEC TO-8

Current → Voltage ↓	Average Forward Amperes 3.2	Average Forward Amperes 1.3
For 120-Volt Line Operation	2N3228	2N3528
For 240-Volt Line Operation	2N3525	2N3529
For High-Voltage Power Supplies	2N4101	2N4102

---

* Formerly Dev. Types TA1222, TA1225, and TA2773, respectively.

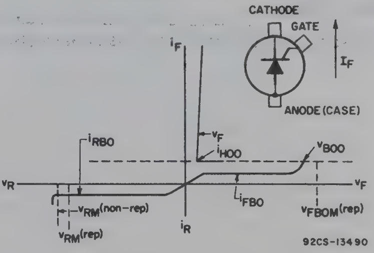
● Formerly Dev. Types TA2597, TA2617, and TA2774, respectively.

▲ The silicon controlled-rectifier is also known as a reverse-blocking triode thyristor.

FEATURES

- Designed especially for high-volume systems
- Readily adaptable for printed-circuit boards and metal heat sinks
- Low switching losses
- High di/dt and dv/dt capabilities
- Shorted emitter gate-cathode construction
- Forward and reverse gate dissipation ratings
- All-diffused construction – assures exceptional uniformity and stability of characteristics
- Direct-soldered internal construction – assures exceptional resistance to fatigue
- Symmetrical gate-cathode construction – provides uniform current density, rapid electrical conduction, and efficient heat dissipation
- All-welded construction and hermetic sealing
- Low leakage currents, both forward and reverse
- Low forward voltage drop at high current levels
- Low thermal resistance

TYPICAL E-I CHARACTERISTIC OF SILICON CONTROLLED-RECTIFIER



Absolute-Maximum Ratings, for Operation with Sinusoidal AC Supply Voltage at a Frequency between 50 and 400 Hz, and with Resistive or Inductive Load

RATINGS	CONTROLLED-RECTIFIER TYPES						UNITS
	2N3228	2N3525	2N4101	2N3528	2N3529	2N4102	
Transient Peak Reverse Voltage (Non-Repetitive), v_{RM}(non-rep)	330	660	700	330	660	700	volts
Peak Reverse Voltage (Repetitive), v_{RM}(rep)	200	400	600	200	400	600	volts
Peak Forward Blocking Voltage (Repetitive), v_{FBOM}(rep)	200	400	600	200	400	600	volts
Forward Current:							
For case temperature (T_C) of + 75°C, and unit mounted on heat sink–							
Average DC value at a conduction angle of 180°, I_{FAV}	3.2	3.2	3.2	—	—	—	amperes
RMS value, I_{FRMS}	5.0	5.0	5.0	—	—	—	amperes
For other conditions, See Fig. 8							
For free-air temperature (T_{FA}) of 25°C, and with no heat sink employed–							
Average DC value at a conduction angle of 180°, I_{FAV}	—	—	—	1.3	1.3	1.3	amperes
RMS value, I_{FRMS}	—	—	—	2.0	2.0	2.0	amperes
For other conditions, See Fig. 9.							
Peak Surge Current, i_{FM}(surge):							
For one cylce of applied principal voltage.							
60 Hz (sinusoidal), T_C = 75°C		60			60		ampere
50 Hz (sinusoidal), T_C = 75°C		50			50		ampere
For more than one cycle of applied voltage.		See Fig. 13			See Fig. 13		
Fusing Current (for SCR protection): T_J = –40 to 100°C, t = 1 to 8.3 ns, I^2t		15			15		ampere^2 second
Rate of Change of Forward Current, di/dt V_{FB} = v_{BOO}(min. value) I_{GT} = 200 mA, 0.5 μs rise time (See waveshapes of Fig. 1)		200			200		amperes/ microsec
Gate Power*:							
Peak, Forward or Reverse, for 10 μs duration, P_{GM} (See Figs. 5 and 6)		13			13		watts
Average, P_{GAV}		0.5			0.5		watt
Temperature:							
Storage, T_{stg}		-40 to +125			-40 to +125		°C
Operating (Case), T_C		-40 to +100			-40 to +100		°C

*Any values of peak gate current or peak gate voltage to give the maximum gate power is permissible.

aracteristics at Maximum Ratings (unless otherwise specified), and at Indicated Case Temperature (T_C)

CHARACTERISTICS	CONTROLLED-RECTIFIER TYPES									UNITS
	2N3228, 2N3528			2N3525, 2N3529			2N4101, 2N4102			
	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
orward Breakover Voltage, v_{BOO}: At T_C = +100°C	200	—	—	400	—	—	600	—	—	volts
eak Blocking Current, at T_C = +100°C:										
Forward, I_{FBOM} $V_{FBO}^p = v_{BOO}$ (min. value)	—	0.10	1.5	—	0.20	3.0	—	0.40	4.0	mA
Reverse, I_{RBOM} $V_{RBO}^p = v_{RM}$ (rep) value	—	0.05	0.75	—	0.10	1.5	—	0.20	2.0	mA
orward Voltage Drop, v_F At a Forward Current of 30 amperes and a T_C = +25°C	—	2.15	2.8	—	2.15	2.8	—	2.15	2.8	volts
C Gate-Trigger Current, I_{GT} At T_C = +25°C (See Fig. 5)	—	8	15	—	8	15	—	8	15	mA(dc)
ate-Trigger Voltage, V_{GT} At T_C = +25°C (See Fig. 5)	—	1.2	2.0	—	1.2	2.0	—	1.2	2.0	volts(dc)
olding Current, i_{HOO} At T_C = +25°C	—	10	20	—	10	20	—	10	20	mA
itical Rate of Applied Forward Voltage, Critical dv/dt $V_{FB} = v_{BOO}$ (min. value), exponential rise, T_C = +100°C (See waveshape of Fig. 2)	10	200	—	10	200	—	10	200	—	volts/ microsecond
urn-On Time, t_{on}, (Delay Time + Rise Time) $V_{FB} = v_{BOO}$ (min. value), i_F = 4.5 amperes, $_{GT}$ = 200 mA, 0.1 μs rise time, T_C = +25°C (See waveshapes of Fig. 3)	0.75	1.5	—	0.75	1.5	—	0.75	1.5	—	microseconds
rn-Off Time, t_{off} $_F$ = 2 amperes, 50 μs pulse width, dv_{FB}/dt = 20 v/μs, di_r/dt = 30 A/μs, I_{GT} = 200 mA, T_C = +75°C (See waveshapes of Fig. 4)	—	15	50	—	15	50	—	15	50	microseconds

	2N3228, 2N3525, 2N4101			2N3528, 2N3529, 2N4102			
	Min.	Typ.	Max.	Min.	Typ.	Max.	
hermal Resistance:							
Junction-to-case	—	—	4	—	—	5	°C/W
Junction-to-ambient	—	—	40	—	—	40	°C/W

WAVESHAPE OF di/dt RATING TEST

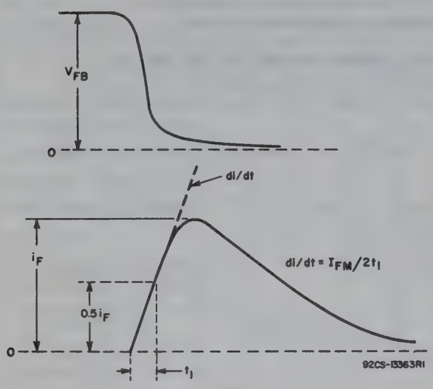


Fig. 1

WAVESHAPE OF CRITICAL dv/dt RATING TEST

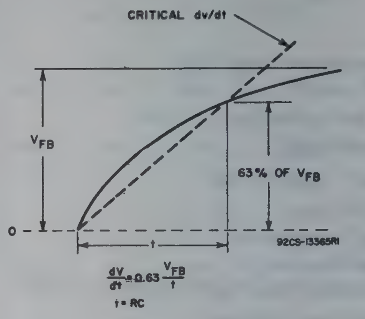


Fig. 2

WAVESHAPE OF t_{on} RATING TEST

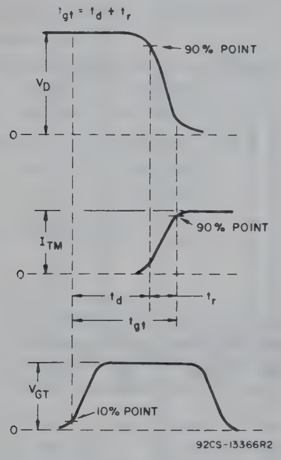


Fig. 3

WAVESHAPE OF t_{off} RATING TEST

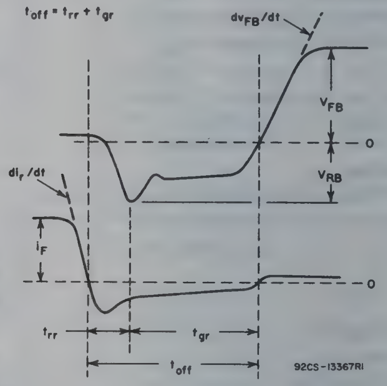


Fig. 4

TERMINAL CONNECTIONS FOR TYPES 2N3228, 2N3525, AND 2N4101

Pin 1 — Gate
Pin 2 — Cathode
Case, Mounting Flange — Anode

TERMINAL CONNECTIONS FOR TYPES 2N3528, 2N3529, AND 2N4102

Pin 1 — Cathode
Pin 2 — Gate
Case, Pin 3 — Anode

FORWARD GATE CHARACTERISTICS

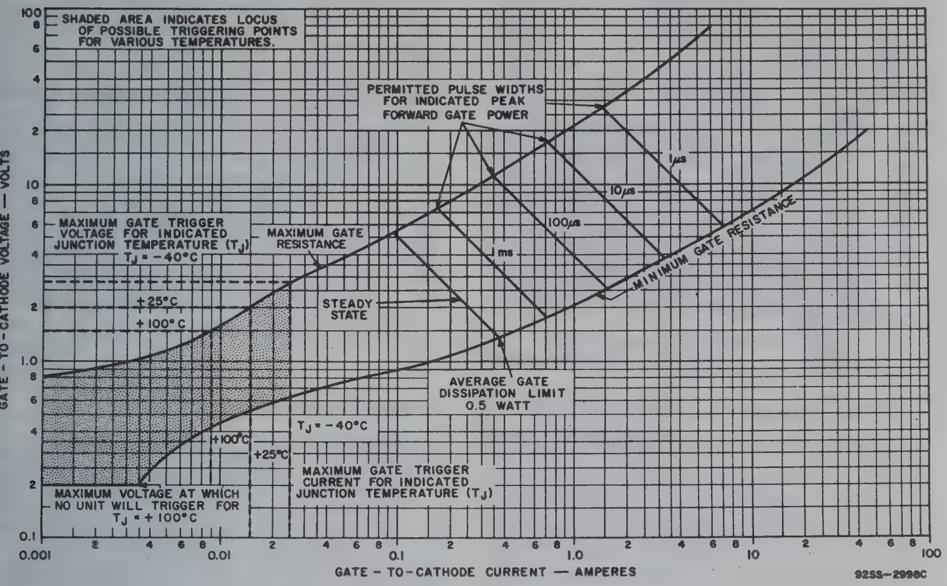


Fig. 5

REVERSE GATE CHARACTERISTICS

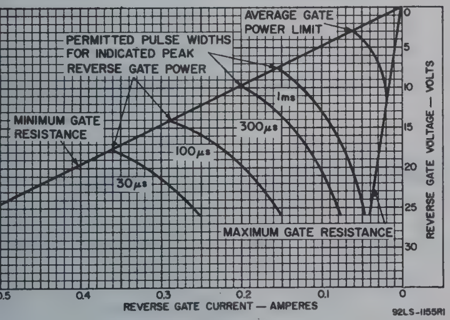


Fig. 6

TURN-ON TIME CHARACTERISTICS

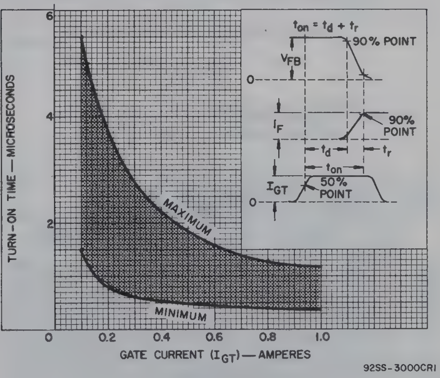


Fig. 7

RATING CHART (CASE TEMPERATURE) FOR TYPES 2N3228, 2N3525, AND 2N4101

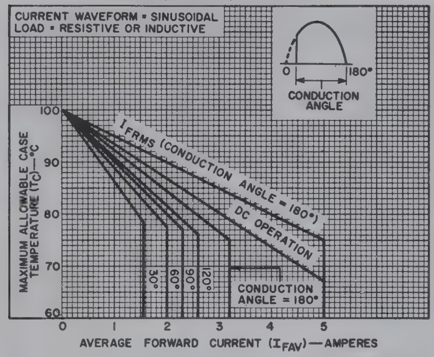


Fig. 8

RATING CHART (FREE-AIR TEMPERATURE) FOR TYPES 2N3528, 2N3529, AND 2N4102

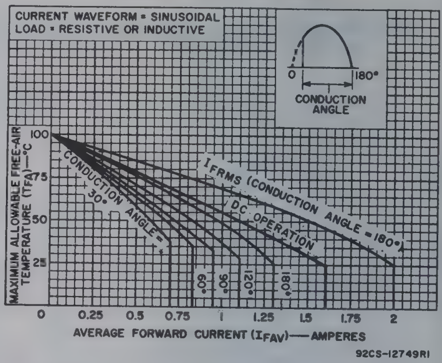


Fig. 9

POWER DISSIPATION CHART FOR ALL TYPES

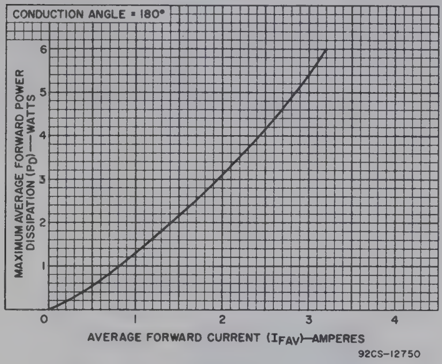


Fig. 10

FORWARD CHARACTERISTICS FOR ALL TYPES

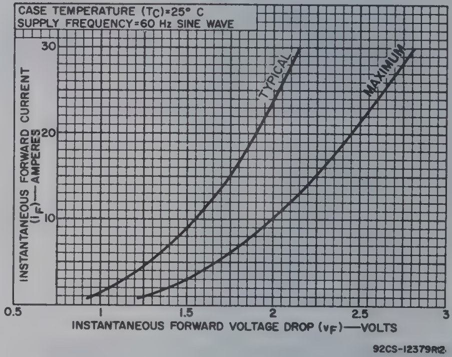


Fig. 11

OPERATION GUIDANCE CHART FOR TYPES 2N3228, 2N3525, AND 2N4101

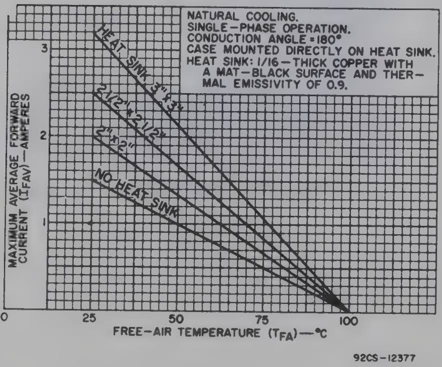


Fig. 12

SURGE CURRENT RATING CHART

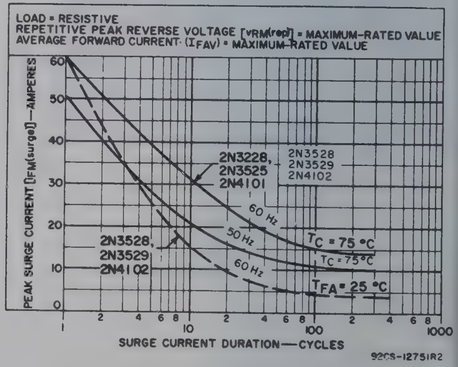


Fig. 13

RCA
Solid State
Division

Thyristors

2N3650 2N3651
2N3652 2N3653
S7430M

A-2N3650 to 2N3653, inclusive, and the S7430M* are diffused silicon controlled rectifiers (reverse-blocking ode thyristors) intended for high-speed switching applicans such as power inverters, switching regulators, and h-current pulse applications. They feature fast turn-off, h dv/dt, and high di/dt characteristics and may be used at quencies up to 25 kHz.

e 2N3650 to 2N3653 have forward and reverse off-state tage ratings of 100, 200, 300, and 400 volts, respectively. oe S7430M has a forward and reverse off-state voltage ing of 600 volts.

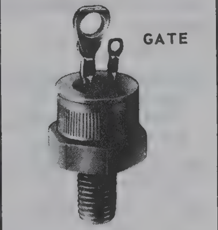
merly RCA Type No. 40735

ATURES

- ast turn-off time – 15 μs max.
- igh di/dt and dv/dt capabilities
- igh peak-current capability
- horted-emitter gate-cathode construction
- orward and reverse gate dissipation ratings
- ll-diffused construction – assures exceptional niformity and stability of characteristics

35-A SILICON CONTROLLED RECTIFIERS

Fast Turn-Off Types for Inverter and Pulse Applications



JEDEC TO-48

- Symmetrical gate-cathode construction – provides uniform current density, rapid electrical conduction, and efficient heat dissipation
- Hermetic construction
- Low thermal resistance

XIMUM RATINGS, *Absolute-Maximum Values:*

		2N3650	2N3651	2N3652	2N3653	S7430M	
N-REPETITIVE PEAK REVERSE VOLTAGE ate Open	V_{RSOM}	150	300	400	500	700	V
N-REPETITIVE PEAK FORWARD VOLTAGE ate Open	V_{DSOM}	150	300	400	500	700	V
PETITIVE PEAK REVERSE VOLTAGE ate Open	V_{RROM}	100	200	300	400	600	V
PETITIVE PEAK OFF-STATE VOLTAGE ate Open	V_{DROM}	100	200	300	400	600	V
AK SURGE (NON-REPETITIVE) ON-STATE CURRENT: or one cycle of applied principal voltage (60 Hz, sinusoidal)	I_{TSM}	← 180 →					A
-STATE CURRENT: or case temperature (T_C) = 25 °C							
Average DC value, conduction angle of 180°	$I_{T(AV)}$	← 25 →					A
RMS value	$I_{T(RMS)}$	← 35 →					A
TE-OF-CHANGE OF ON-STATE CURRENT: DM = $V_{(BO)O}$, I_{GT} = 200 mA, t_r = 0.1 μs (See Fig. 2)	di/dt	← 400 →					A/μs
SING CURRENT (for SCR protection): J = –65 to 120°C, t = 1 to 8.3 ms	I^2t	← 165 →					A^2s
TE POWER DISSIPATION							
EAK FORWARD (for 10 μs max.)	P_{GM}	← 40 →					W
VERAGE (averaging time = 10 ms, max.)	$P_{G(AV)}$	← 1 →					W
MPERATURE RANGE							
orage		← -65 to 150 →					°C
perating (Case)		← -65 to 120 →					°C
oldering (10 s max. for case)		← 225 →					°C
UD TORQUE:	τ_s						
ecommended		← 35 →					in-1b
aximum (DO NOT EXCEED)		← 50 →					in-1b

accordance with JEDEC registration data format (JS-14, RDF1)--
oplies to the JEDEC (2N-Series) types only.

ELECTRICAL CHARACTERISTICS, *At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified*

CHARACTERISTIC	SYMBOL	LIMITS															UNIT
		Type 2N3650			Type 2N3651			Type 2N3652			Type 2N3653			Type S7430M			
		MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	
INSTANTANEOUS FORWARD BREAKOVER VOLTAGE: Gate Open, T_C = 120 °C	$v_{(BO)O}$	100	–	–	200	–	–	300	–	–	400	–	–	600	–	–	V
* PEAK OFF-STATE CURRENT: (Gate Open, T_C = 120 °C) FORWARD, $V_{DO} = V_{DROM}$	I_{DOM}	–	–	6	–	–	6	–	–	5.5	–	–	4	–	–	3	mA
REVERSE, $V_{RO} = V_{RROM}$	I_{RROM}	–	–	6	–	–	6	–	–	5.5	–	–	4	–	–	3	
* INSTANTANEOUS ON-STATE VOLTAGE: For i_T = 25 A, T_C = 25 °C	v_T	–	–	2.05	–	–	2.05	–	–	2.05	–	–	2.05	–	–	2.05	V
DC GATE TRIGGER CURRENT: V_D = 6 V (DC), R_L = 4 Ω, T_C = 25 °C	I_{GT}	–	80	180	–	80	180	–	80	180	–	80	180	–	80	180	mA
V_D = 6 V (DC), R_L = 2 Ω, T_C = -65 °C		–	150	500*	–	150	500*	–	150	500*	–	150	500*	–	150	500	
DC GATE TRIGGER VOLTAGE: V_D = 6 V (DC), R_L = 4 Ω, T_C = 25 °C	V_{GT}	–	1.5	3	–	1.5	3	–	1.5	3	–	1.5	3	–	1.5	3	V
$V_D = V_{DROM}$, R_L = 200 Ω, T_C = 120 °C		0.25*	–	–	0.25*	–	–	0.25*	–	–	0.25*	–	–	0.25	–	–	
V_D = 6 V (DC), R_L = 2 Ω, T_C = -65 °C		–	2	4.5*	–	2	4.5*	–	2	4.5*	–	2	4.5*	–	2	4.5	
INSTANTANEOUS HOLDING CURRENT: Gate Open At T_C = 25 °C	i_{HO}	–	75	150	–	75	150	–	75	150	–	75	150	–	75	150	mA
* At T_C = -65 °C		–	150	350	–	150	350	–	150	350	–	150	350	–	150	350	
* CRITICAL RATE-OF-RISE OF OFF-STATE VOLTAGE: $V_{DO} = V_{DROM}$ Exponential rise, T_C = 120 °C, (See Fig. 4.)	dv/dt	200	–	–	200	–	–	200	–	–	200	–	–	200	–	–	V/μ
CIRCUIT COMMUTATED TURN-OFF TIME (Rectangular Pulse): $V_{DX} = V_{DROM}$, i_T = 10 A (pulse duration = 50 μs), I_{GT} = 200 mA at turn-on, -di/dt = 5 A/μs, dv/dt = 200 V/μs, V_{RX} = 15 min., V_{GK} = 0 V (at turn-off), T_C = 120 °C (See Fig. 4 & 5)	t_q	–	11	15	–	11	15	–	11	15	–	11	15	–	11	15	μs
CIRCUIT COMMUTATED TURN-OFF TIME (Half-Sinusoidal Waveform): $V_{DX} = V_{DROM}$, i_T = 100 A (pulse duration = 2 μs), I_{GT} = 200 mA dv/dt = 200 V/μs, V_{RX} = 30 V min., V_{GK} = 0 V (at turn-off), T_C = 115 °C (See Fig. 6 & 7)	t_q	–	12	15*	–	12	15*	–	12	15*	–	12	15*	–	12	15	μs
* THERMAL RESISTANCE: Junction-to-Case	θ_{J-C}	–	–	1.7	–	–	1.7	–	–	1.7	–	–	1.7	–	–	1.7	°C/W

*In accordance with JEDEC registration data format (JS-14, RD 1) -- applies to the JEDEC (2N-Series) types only.

TERMINAL CONNECTIONS
Terminal 1 (Small Lug) – Gate
Terminal 2 (Large Lug) – Cathode
Terminal 3 (Stud) – Anode

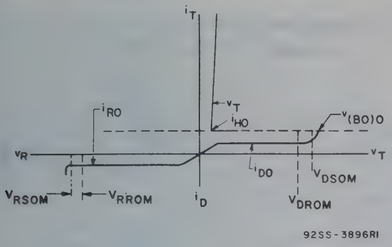


Fig. 1—Principal voltage-current characteristic.

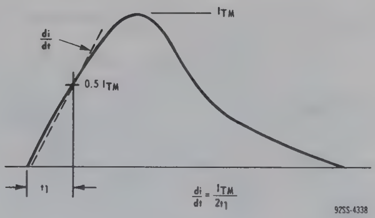


Fig. 2—Rate of change of on-state current with time (defining di/dt).

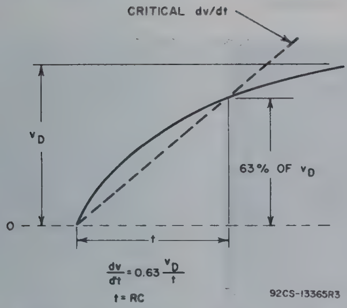


Fig. 3—Rate of rise of off-state voltage with time (defining dv/dt).

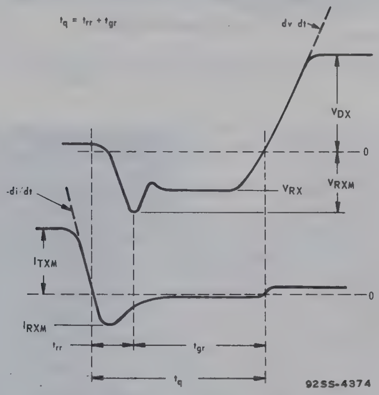
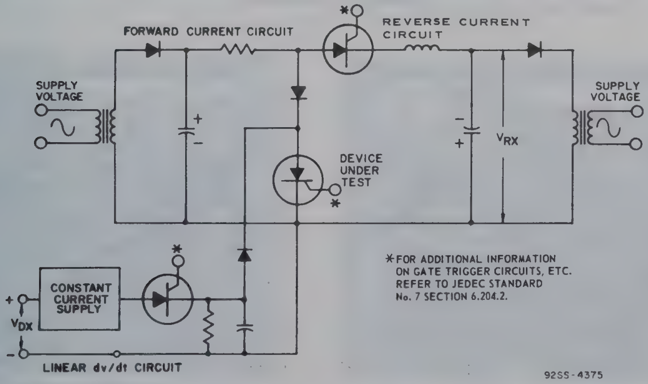


Fig. 4—Relationship between off-state voltage, reverse voltage, on-state current, and reverse current, showing reference points defining turn-off time (t_q), rectangular pulse.


FORWARD CURRENT CIRCUIT
REVERSE CURRENT CIRCUIT
SUPPLY VOLTAGE
SUPPLY VOLTAGE
VRX
DEVICE UNDER TEST
CONSTANT CURRENT SUPPLY
VDX
LINEAR dv/dt CIRCUIT
92SS-4375

*FOR ADDITIONAL INFORMATION ON GATE TRIGGER CIRCUITS, ETC. REFER TO JEDEC STANDARD No. 7 SECTION 6.204.2.

Fig. 5—Circuit used to measure turn-off time (t_q), rectangular pulse.

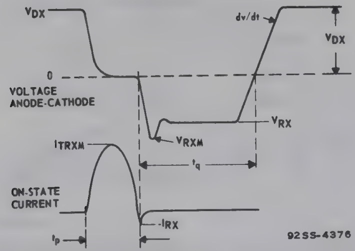


Fig. 6—Relationship between off-state voltage, reverse voltage, on-state current, and reverse current showing reference points for specification of turn-off time (t_q), half sine wave pulse.

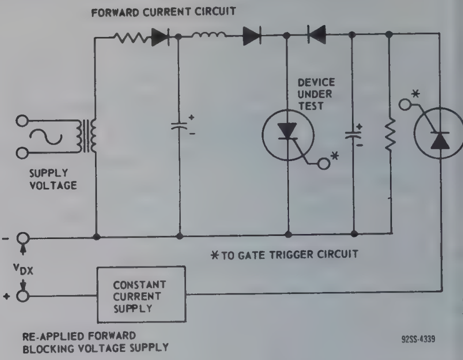

FORWARD CURRENT CIRCUIT
DEVICE UNDER TEST
SUPPLY VOLTAGE
*
*
*TO GATE TRIGGER CIRCUIT
VDX
CONSTANT CURRENT SUPPLY
RE-APPLIED FORWARD BLOCKING VOLTAGE SUPPLY
92SS-4339

Fig. 7—Circuit used to measure turn-off time (t_q), half sine wave pulse.

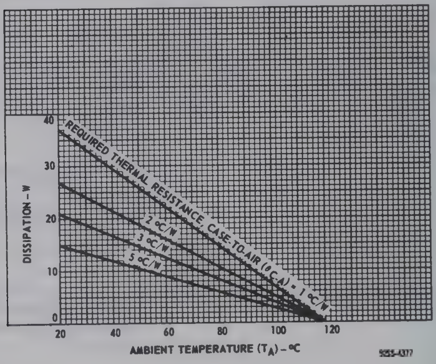


Fig. 8—Heat sink guidance.

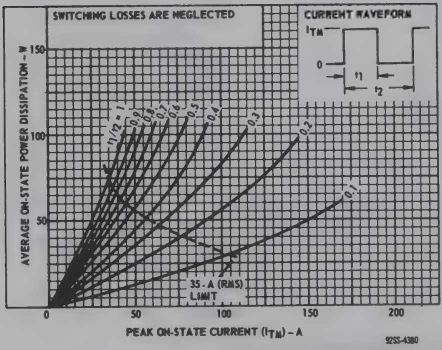


Fig. 9—Power dissipation vs. on-state current.

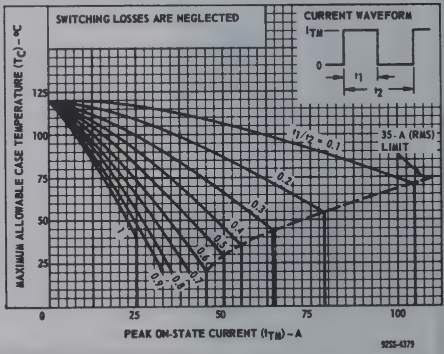


Fig.10—Maximum allowable case-temperature vs. on-state current.

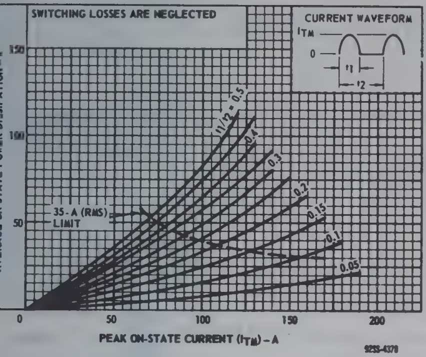


Fig. 11—Power dissipation vs. on-state current.

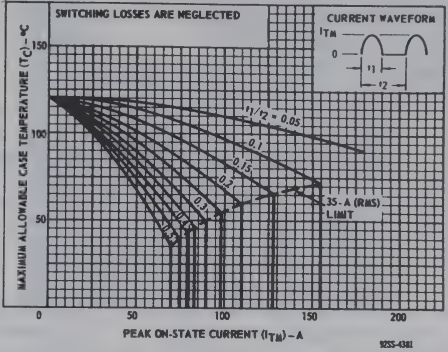


Fig. 12—Maximum allowable case-temperature vs. on-state current.

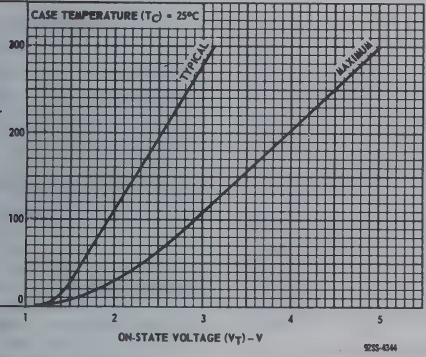


Fig. 13—Variation of on-state current with on-state voltage.

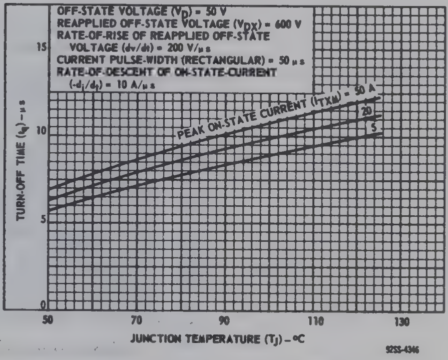


Fig. 14—Typical variation of turn-off time with junction temperature (rectangular pulse).

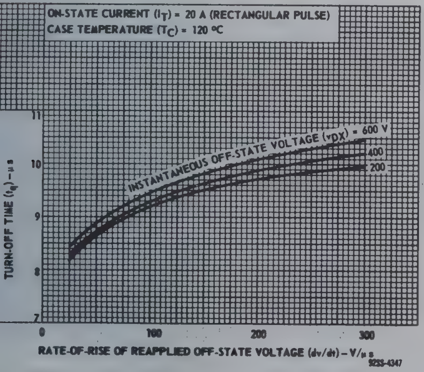


Fig. 15—Typical variation of turn-off time with rate of rise of reapplied off-state voltage (rectangular pulse).

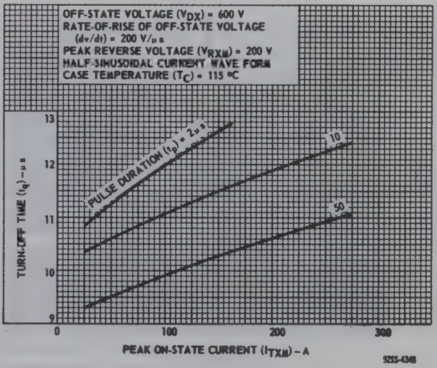


Fig. 16—Typical variation of turn-off time with peak on-state current (half-sinusoidal pulse).

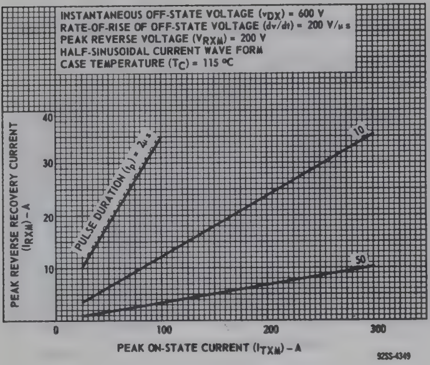


Fig. 17—Typical variation of peak reverse recovery current with peak on-state current (half) sinusoidal pulse).

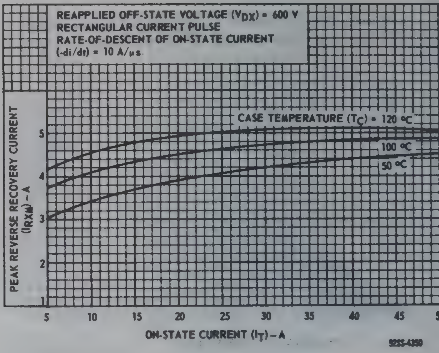


Fig. 18—Typical variation of peak reverse-recovery current with on-state current.

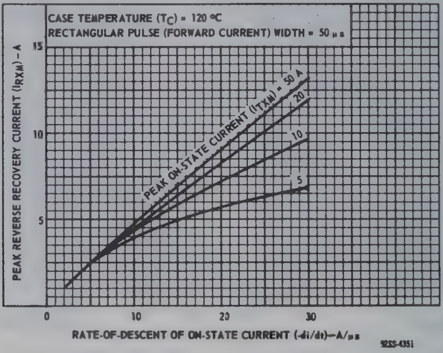


Fig. 19—Typical variation of peak reverse recovery current with rate of descent of on-state current.

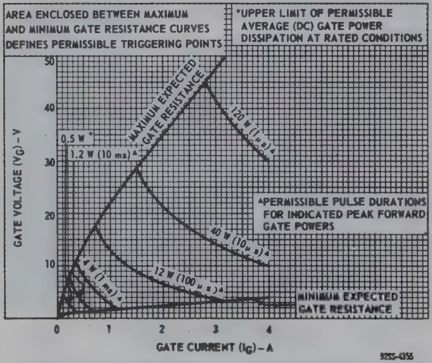


Fig. 20—Typical forward-biased gate characteristics.

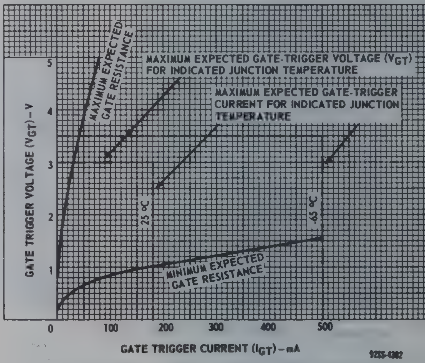


Fig. 21—Typical gate trigger characteristics.

RCA
Solid State Division

Thyristors

2N3654 2N3655
2N3656 2N3657
2N3658 S7432M

Cathode
Gate
Anode

EDEC TO-48 H-1601

35-A Silicon Controlled Rectifiers

For Inverter Applications

Features:

- Fast turn-off time — 10 μs max.
- High di/dt and dv/dt capabilities
- Shorted-emitter gate-cathode construction . . . contains an internally diffused resistor between gate and cathode
- Low thermal resistance
- Center gate construction . . . provides rapid uniform gate-current spreading for faster turn-on with substantially reduced heating effects

ese RCA types are all-diffused, silicon controlled rectifiers signed for high-frequency power-switching applications such inverters, switching regulators, and high-current pulse applications. These types may be used at frequencies up to 25 kHz.

		2N3654	2N3655	2N3656	2N3657	2N3658	S7432M	
XIMUM RATINGS, *Absolute-Maximum Values:*								
ON-REPETITIVE PEAK REVERSE VOLTAGE:●								
Gate Open	V_{RSOM}	75	150	300	400	500	700	V
ON-REPETITIVE PEAK OFF-STATE VOLTAGE:●								
Gate Open	V_{DSOM}	75	150	300	400	500	700	V
EPETITIVE PEAK REVERSE VOLTAGE:●								
Gate Open	V_{RROM}	50	100	200	300	400	600	V
EPETITIVE PEAK OFF-STATE VOLTAGE:●								
Gate Open	V_{DROM}	50	100	200	300	400	600	V
N-STATE CURRENT:								
$T_C = 40^\circ C$, conduction angle = 180°:								
RMS	$I_{T(RMS)}$	35						A
Average	$I_{T(AV)}$	25						A
EAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}							
For one full cycle of applied principal voltage 60 Hz (sinusoidal)		180						A
ATE OF CHANGE OF ON-STATE CURRENT:								
$V_D = V_{DROM}$, $I_{GT} = 200$ mA, $t_r = 0.1$ μs (See Fig. 15)	di/dt	400						A/μs
USING CURRENT (for SCR protection):								
$T_J = -65$ to $120^\circ C$, t = 1 to 8.3 ms	I^2t	165						A^2s
ATE POWER DISSIPATION:■								
Peak Forward (for 10 μs max., See Fig. 7)	P_{GM}	40						W
Average (averaging time = 10 ms max.)	$P_{G(AV)}$	1						W
EMPERATURE RANGE:▲								
Storage	T_{stg}	−65 to 150						°C
Operating (Case)	T_C	−65 to 120						°C
ERMINAL TEMPERATURE (During soldering):	T_T							
For 10 s max. (terminals and case)		225						°C
TUD TORQUE:	τ_s							
Recommended		35						in-lb
Maximum (DO NOT EXCEED)		50						in-lb

accordance with JEDEC registration data format (JS-14, RDF-1) filed for the JEDEC (2N series) types.
hese values do not apply if there is a positive gate signal. Gate must be open or negatively biased.
ny product of gate current and gate voltage which results in a gate power less than the maximum is permitted.
or temperature measurement reference point, see Dimensional Outline.

ELECTRICAL CHARACTERISTICS

At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS FOR ALL TYPES Except as Specified MIN.	 TYP.	 MAX.	UNITS
* Peak Off-State Current: (Gate open, T_C = 120°C) Forward Current (I_{DOM}) at $V_D = V_{DROM}$ Reverse Current (I_{ROM}) at $V_R = V_{RROM}$	I_{DOM} or I_{ROM}				mA
2N3654, 2N3655, 2N3656, S7432M		–	–	6	
2N3657		–	–	5.5	
2N3658		–	–	4	
* Instantaneous On-State Voltage: i_T = 25 A (peak), T_C = 25°C	v_T	–	–	2.05	V
Instantaneous Holding Current: Gate open, T_C = 25°C	i_{HO}	–	75	150	mA
T_C = –65°C		–	150	350*	
* Critical Rate of Rise of Off-State Voltage: $V_D = V_{DROM}$, exponential voltage rise, Gate open, T_C = 120°C (See Fig. 16)	dv/dt	200	–	–	V/µs
DC Gate Trigger Current: V_D = 6 V (dc), R_L = 4 Ω, T_C = 25°C	I_{GT}	–	80	180	mA
V_D = 6 V (dc), R_L = 2 Ω, T_C = –65°C		–	150	500*	
DC Gate Trigger Voltage: V_D = 6 V (dc), R_L = 4 Ω, T_C = 25°C	V_{GT}	–	1.5	3	V
$V_D = V_{DROM}$, R_L = 200 Ω, T_C = 120°C		0.25*	–	–	
V_D = 6 V (dc), R_L = 2 Ω, T_C = –65°C		–	2	4.5*	
* Circuit Commutated Turn-Off Time: (Rectangular Pulse) $V_{DX} = V_{DROM}$, i_T = 10 A, pulse duration = 50 µs, dv/dt = 200 V/µs, – di/dt = –5 A/µs, I_{GT} = 200 mA, V_{RX} = 15 V min., V_{GK} = 0 V (at turn-off), T_C = 120°C (See Figs. 19 & 20).	t_q	–	–	10	µs
* Circuit Commutated Turn-Off Time: (Sinusoidal Pulse) $V_{DX} = V_{DROM}$, i_T = 100 A, pulse duration = 2 µs, dv/dt = 200 V/µs, V_{RX} = 30 V min., V_{GK} = 0 V (at turn-off) T_C = 115°C (See Figs. 17 & 18)	t_q	–		10	µs
* Thermal Resistance Junction-to-Case: Steady-State	$R_{\theta\text{-}JC}$	–	–	1.7	°C/W

* In accordance with JEDEC registration data format (JS-14, RDF-1) filed for the JEDEC (2N-series) types.

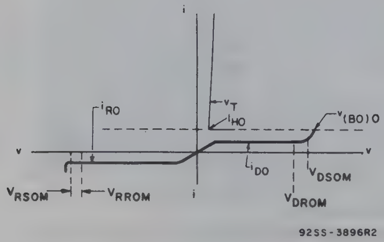


Fig. 1 – Principal voltage-current characteristic.

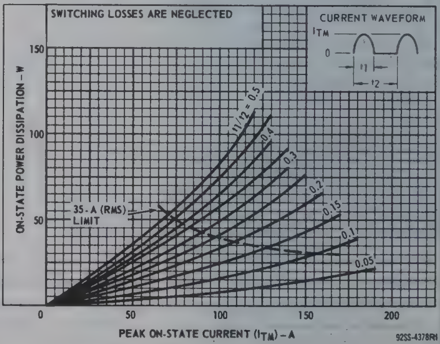


Fig. 2 – Power dissipation vs. peak on-state current.

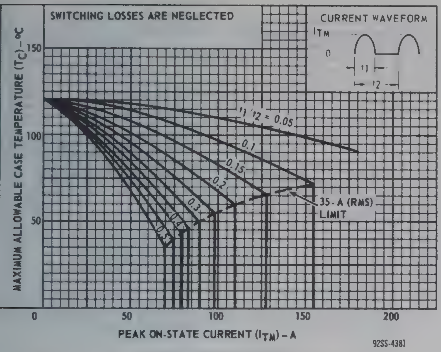


Fig. 3 – Maximum allowable case-temperature vs. peak on-state current.

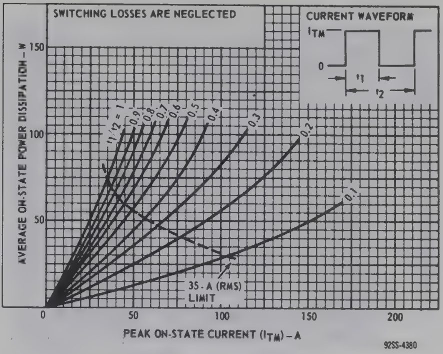


Fig. 4 – Power dissipation vs. peak on-state current.

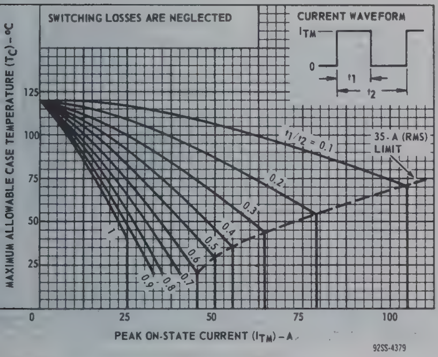


Fig. 5 – Maximum allowable case-temperature vs. peak on-state current.

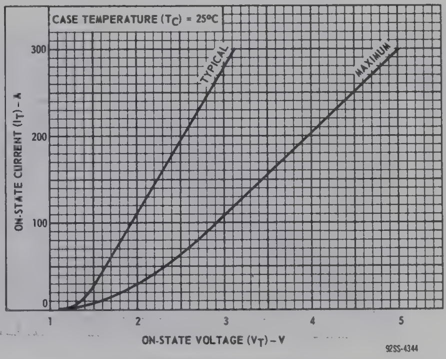


Fig. 6 – Variation of on-state current with on-state voltage.

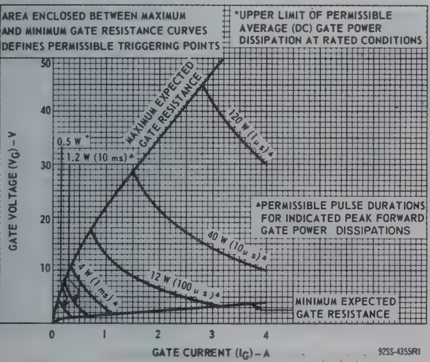


Fig. 7 – Typical forward-biased gate characteristics.

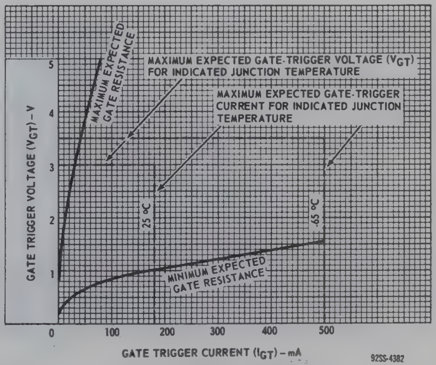


Fig. 8 – Typical gate-trigger characteristics.

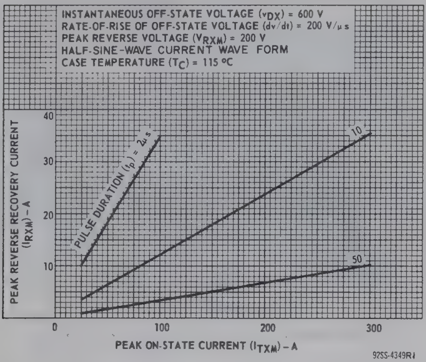


Fig. 9 — Typical variation of peak reverse-recovery current with peak on-state current (half-sine-wave pulse).

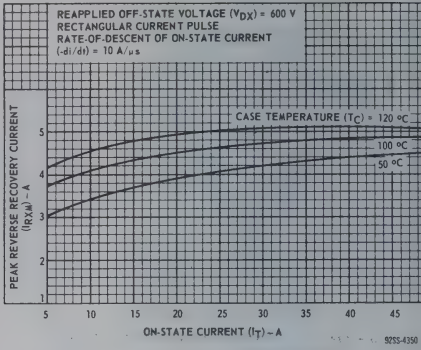


Fig. 10 — Typical variation of peak reverse-recovery current wi on-state current (rectangular pulse).

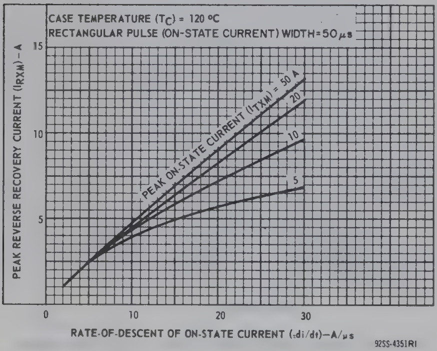


Fig. 11 — Typical variation of peak reverse-recovery current with rate-of-descent of on-state current (rectangular pulse).

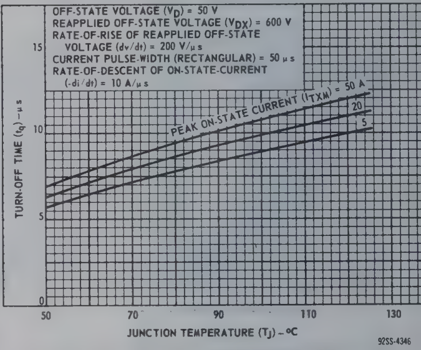


Fig. 12 — Typical variation of turn-off time with junction temperature (rectangular pulse).

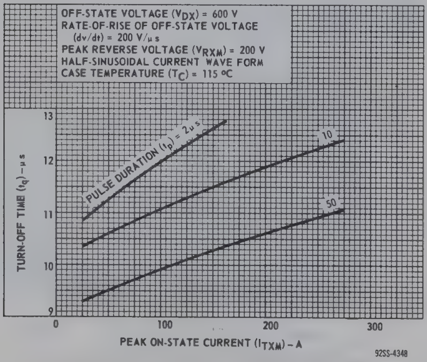


Fig. 13 — Typical variation of turn-off time with peak on-state current (half-sine-wave pulse).

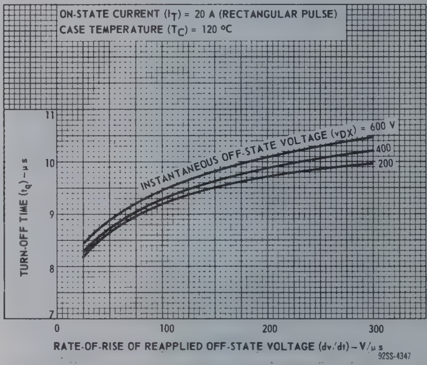


Fig. 14 — Typical variation of turn-off time with rate-of-rise of reapplied off-state voltage (rectangular pulse).

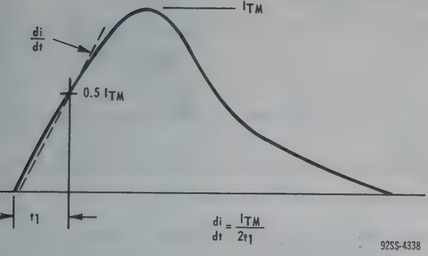


Fig. 15 – Rate-of-change of on-state current with time (defining di/dt).

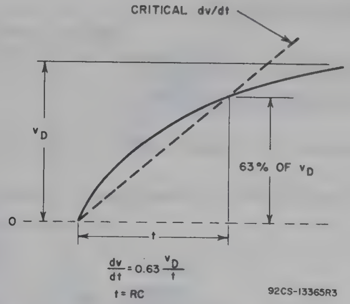
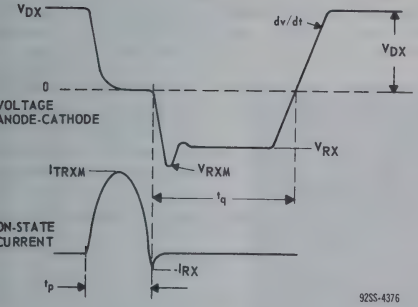


Fig. 16 – Rate-of-rise of off-state voltage with time (defining dv/dt).



ig. 17 – Relationship between off-state voltage, reverse voltage, on-state current, and reverse current showing reference points for specification of turn-off time (t_q), half-sine-wave pulse.

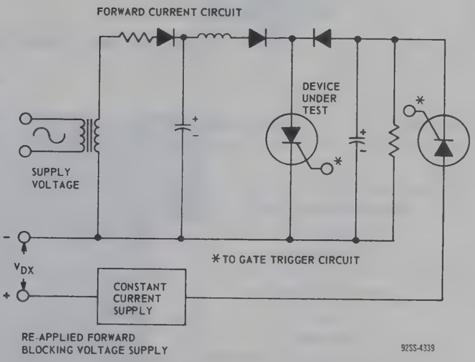

FORWARD CURRENT CIRCUIT
DEVICE
UNDER
TEST
*
SUPPLY
VOLTAGE
*
-
VDX
+
*TO GATE TRIGGER CIRCUIT
CONSTANT
CURRENT
SUPPLY
RE-APPLIED FORWARD
BLOCKING VOLTAGE SUPPLY
92SS-4339

Fig. 18 – Circuit used to measure turn-off time (t_q), half-sine-wave pulse.

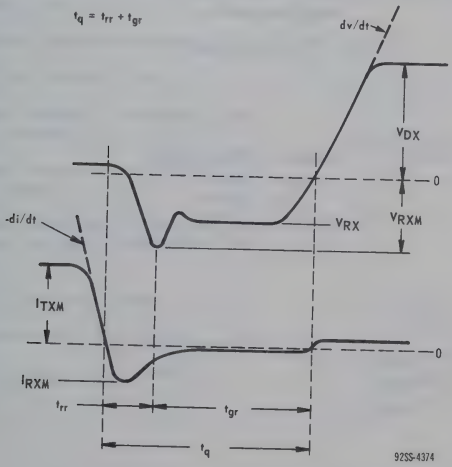
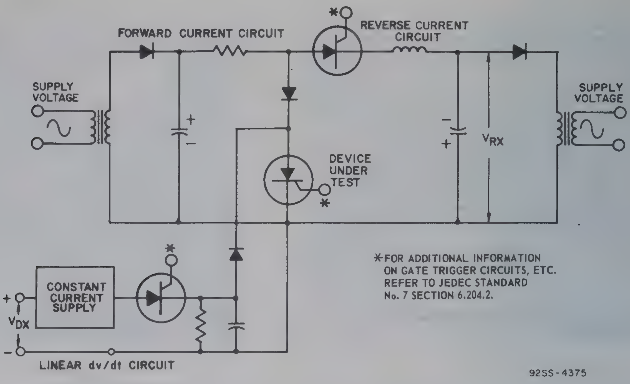


Fig. 19 – Relationship between off-state voltage, reverse voltage, on-state current, and reverse current showing reference points defining turn-off time (t_q), rectangular pulse.


FORWARD CURRENT CIRCUIT
REVERSE CURRENT CIRCUIT
SUPPLY VOLTAGE
SUPPLY VOLTAGE
+
–
–
+
VRX
DEVICE UNDER TEST
*
*
*
CONSTANT CURRENT SUPPLY
+
VDX
–
LINEAR dv/dt CIRCUIT
92SS-4375

*FOR ADDITIONAL INFORMATION ON GATE TRIGGER CIRCUITS, ETC. REFER TO JEDEC STANDARD No. 7 SECTION 6.204.2.

Fig. 20—Circuit used to measure turn-off time (t_q), rectangular pulse.

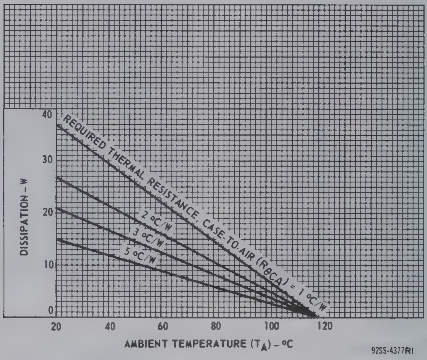


Fig. 21 — Heat sink guidance.

TERMINAL CONNECTIONS

No. 1 — Gate
No. 2 — Cathode
Case, No. 3 — Anode

RCA
Solid State
Division

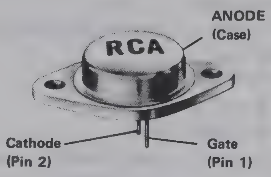
Thyristors

2N3668 2N3670
2N3669 2N4103

All-Diffused SCR's for Low-Cost Power-Control and Power-Switching Applications

RCA 2N3668*, 2N3669*, 2N3670*, and 2N4103* are ll-diffused, three-junction, silicon controlled-rectifiers SCR's▲). They are intended for use in power-control and ower-switching applications requiring a blocking voltage apability of up to 600 volts and a forward-current capa-ility of 12.5 amperes (rms value) or 8 amperes (average alue) at a case temperature of 80°C.

The 2N3668 is designed for low-voltage power sup-lies, the 2N3669 for direct operation from 120-volt line upplies, the 2N3670 for direct operation from 240-volt ine supplies, and the 2N4103 for high-voltage power upplies.



JEDEC TO-3

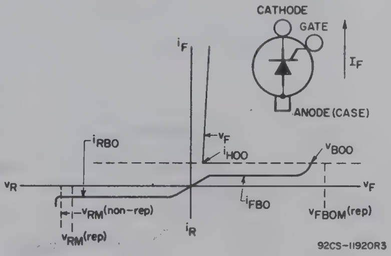
H-1570

2N3668	For Low-Voltage Power Supplies
2N3669	For 120-Volt Line Operation
2N3670	For 240-Volt Line Operation
2N4103	For High-Voltage Power Supplies

FEATURES

- Low switching losses
- High di/dt and dv/dt capabilities
- Shorted emitter gate-cathode construction
- Forward and reverse gate dissipation ratings
- Designed especially for high-volume systems
- All-diffused construction – assures exceptional uniformity and stability of characteristics
- Direct-soldered internal construction – assures exceptional resistance to fatigue
- Symmetrical gate-cathode construction – provides uniform current density, rapid electrical conduction, and efficient heat dissipation
- All-welded construction and hermetic sealing
- Low leakage currents, both forward and reverse
- Low forward voltage drop at high current levels
- Low thermal resistance

TYPICAL E-I CHARACTERISTIC OF SILICON CONTROLLED-RECTIFIER



Formerly Dev. Types TA2621, TA2598, TA2618, and TA2775, respectively.

The silicon controlled-rectifier is also known as a reverse-blocking triode thyristor.

Absolute-Maximum Ratings, for Operation with Sinusoidal AC Supply Voltage at a Frequency between 50 and 400 Hz, and with Resistive or Inductive Load

RATINGS	CONTROLLED-RECTIFIER TYPES				UNITS
	2N3668	2N3669	2N3670	2N4103	
Transient Peak Reverse Voltage (Non-Repetitive), v_{RM}(non-rep)	150	330	660	700	volts
Peak Reverse Voltage (Repetitive), v_{RM}(rep)	100	200	400	600	volts
Peak Forward Blocking Voltage (Repetitive), v_{FBOM}(rep)	100	200	400	600	volts
Forward Current:					
For case temperature (T_C) of +80° C					
Average DC value at a conduction angle of 180°, I_{FAV}	8	8	8	8	amperes
RMS value, I_{FRMS}	12.5	12.5	12.5	12.5	amperes
For other conditions, see Fig. 8					
Peak Surge Current, i_{FM}(surge):					
For one cycle of applied voltage	200	200	200	200	amperes
For one cycle of applied principal voltage					
60 Hz (sinusoidal), T_C = 80°C	200	200	200	200	amperes
50 Hz (sinusoidal), T_C = 80°C	170	170	170	170	amperes
For more than one cycle of applied voltage	See Fig. 10	See Fig. 10	See Fig. 10	See Fig. 10	
Fusing Current (for SCR protection):					
T_J = –40 to 100°C, t = 1 to 8.3 ms, I^2t	170	170	170	170	ampere^2 second
Rate of Change of Forward Current, di/dt V_{FB} = v_{BOO}(min. value) I_{GT} = 200mA, 0.5 μs rise time (See waveshapes of Fig. 1)	200	200	200	200	amperes microsec
Gate Power*:					
Peak, Forward or Reverse, for 10 μs duration, P_{GM} (See Figs. 5 and 6)	40	40	40	40	watts
Average, P_{GAV}	0.5	0.5	0.5	0.5	watt
Temperature:					
Storage, T_{stg}●	-40 to +125	-40 to +125	-40 to +125	-40 to +125	°C
Operating (Case), T_C	-40 to +100	-40 to +100	-40 to +100	-40 to +100	°C

* Any values of peak gate current or peak gate voltage to give the maximum gate power is permissible.

● Temperature reference point is within 1/8 in. (3.17 mm) of the center of the underside of unit.

WAVESHAPE OF di/dt RATING TEST

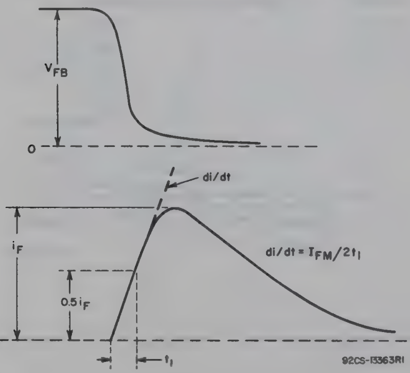


Fig. 1

WAVESHAPE OF CRITICAL dv/dt RATING TEST

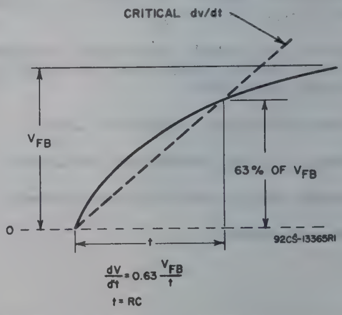


Fig. 2

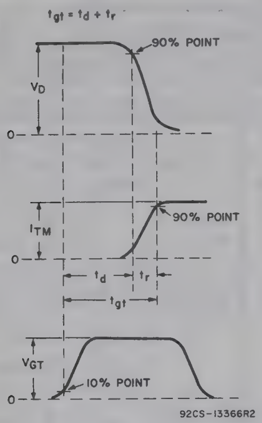
aracteristics at Maximum Ratings (unless otherwise specified), and at Indicated Case Temperature (T_C)

CHARACTERISTICS	CONTROLLED-RECTIFIER TYPES												UNITS
	2N3668			2N3669			2N3670			2N4103			
	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
ak Repetitive Blocking Voltage, DROM T_C = +100°C	100	–	–	200	–	–	400	–	–	600	–	–	volts
k Blocking Current, at T_C = +100°C:													
rward, I_{DOM} D = V_{DROM}	–	0.2	2	–	0.25	2.5	–	0.3	3	–	0.35	4	mA
everse, I_{ROM} R = V_{RROM}	–	0.05	1	–	0.1	1.25	–	0.2	1.5	–	0.3	3	mA
ward Voltage Drop, v_F a Forward Current of 25 amperes and T_C = +25°C (See Fig. 11)	–	1.5	1.8	–	1.5	1.8	–	1.5	1.8	–	1.5	1.8	volts
Gate-Trigger Current, I_{GT}: T_C = +25°C (See Fig. 5)	1	20	40	1	20	40	1	20	40	1	20	40	mA(dc)
e-Trigger Voltage, V_{GT}: T_C = +25°C (See Fig. 5)	–	1.5	2	–	1.5	2	–	1.5	2	–	1.5	2	volts (dc)
ding Current, i_{HOO}: T_C = +25°C	0.5	25	50	0.5	25	50	0.5	25	50	0.5	25	50	mA
ical Rate of Applied Forward Voltage, itical dv/dt $/_{FB}$ = v_{BOO} (min.value), exponential rise, $_C$ = +100°C (See waveshape of Fig. 2)	10	100	–	10	100	–	10	100	–	10	100	–	volts/ microsecond
n-On Time, t_{on}, (Delay Time + Rise Time) $_{FB}$ = v_{BOO} (min. value), i_F = 8 amperes, $_T$ = 200 mA, 0.1 μs rise time, = +25°C (See waveshapes of Fig. 3)	0.75	1.25	–	0.75	1.25	–	0.75	1.25	–	0.75	1.25	–	microseconds
n-Off Time, t_{off}, (Reverse Recovery Time Gate Recovery Time) = 8 amperes, 50 μs pulse width, $_{FB}$/dt = 20 v/μs, /dt = 30 A/μs, I_{GT} = 200 mA, = +80°C (See waveshapes of Fig. 4)	–	20	50	–	20	50	–	20	50	–	20	50	microseconds
rmal Resistance, Junction-to-Case	–	–	1.7	–	–	1.7	–	–	1.7	–	–	1.7	°C/W

TERMINAL CONNECTIONS

Pin 1 — Gate
Pin 2 — Cathode
Case, Mounting Flange — Anode

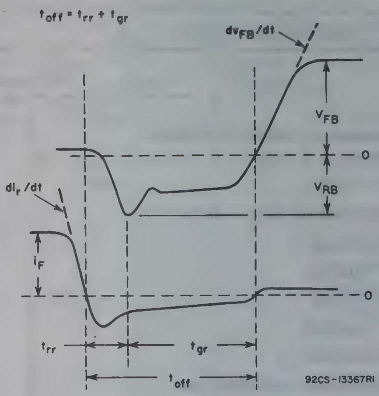
WAVESHAPE OF t_{on} RATING TEST



$t_{gt} = t_d + t_r$
90% POINT
V_D
0
I_{TM}
90% POINT
0
t_d
t_r
t_{gt}
V_{GT}
10% POINT
0
92CS-13366R2

Fig. 3

WAVESHAPE OF t_{off} RATING TEST



$t_{off} = t_{rr} + t_{gr}$
dv_{FB}/dt
V_{FB}
0
V_{RB}
dI_r/dt
I_F
0
t_{rr}
t_{gr}
t_{off}
92CS-13367R1

Fig. 4

FORWARD GATE CHARACTERISTICS

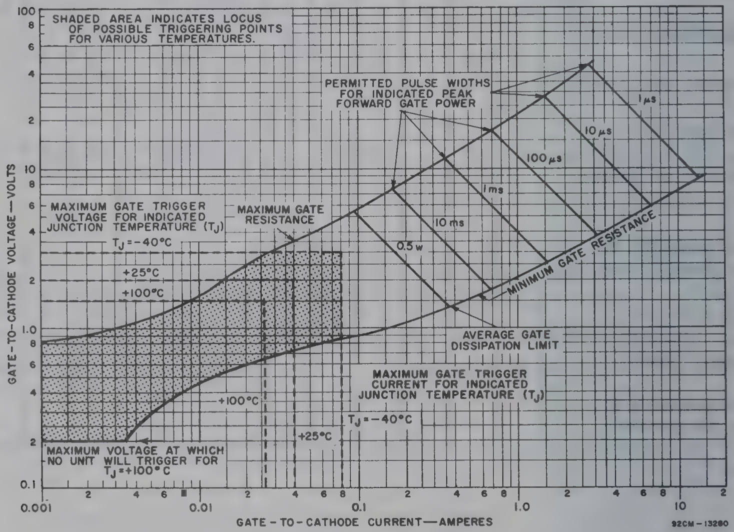


Fig. 5

REVERSE GATE CHARACTERISTICS

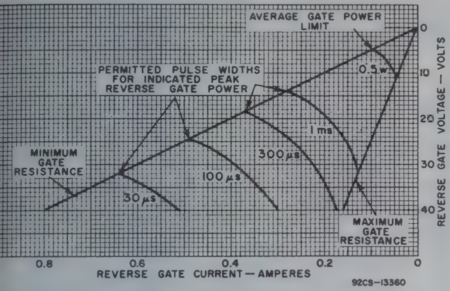


Fig. 6

TURN-ON TIME CHARACTERISTICS

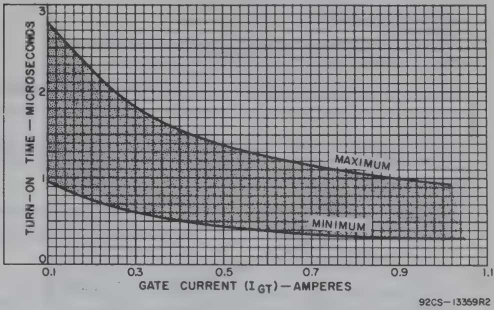


Fig. 7

RATING CHART (CASE TEMPERATURE)

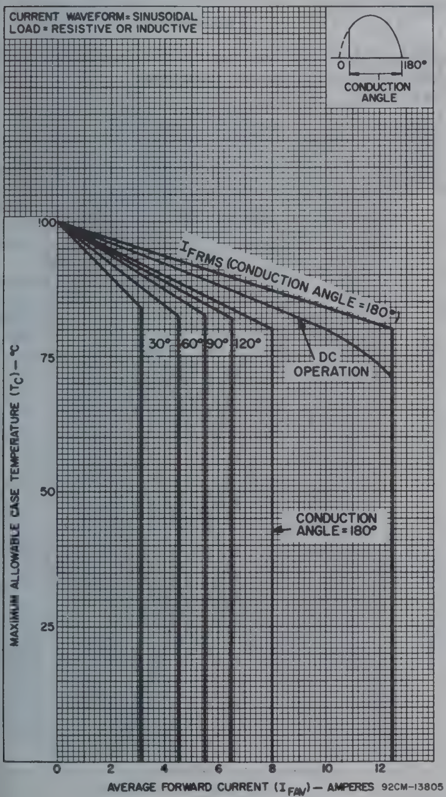


Fig. 8

POWER DISSIPATION

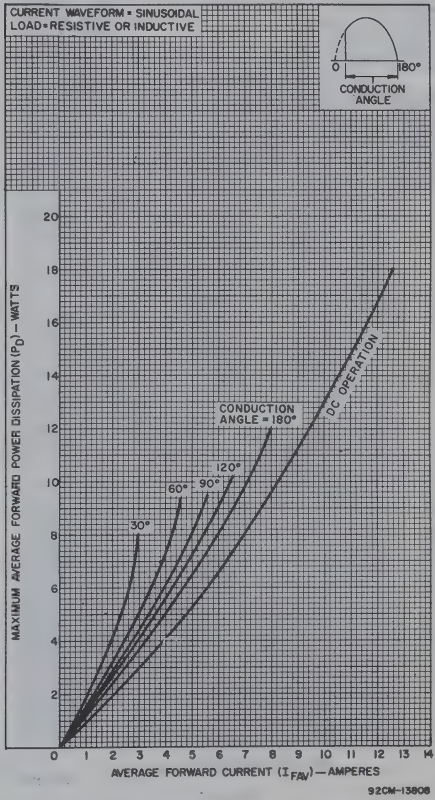
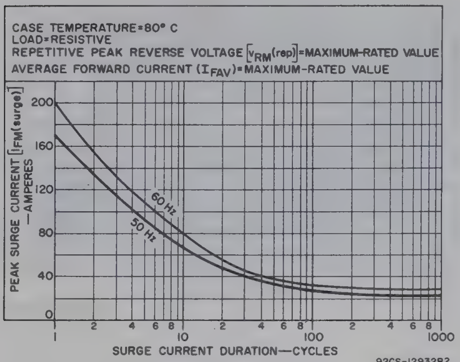


Fig. 9

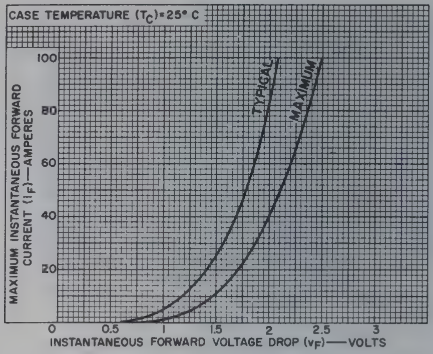
SURGE CURRENT RATING



92CS-12932R2

Fig. 10

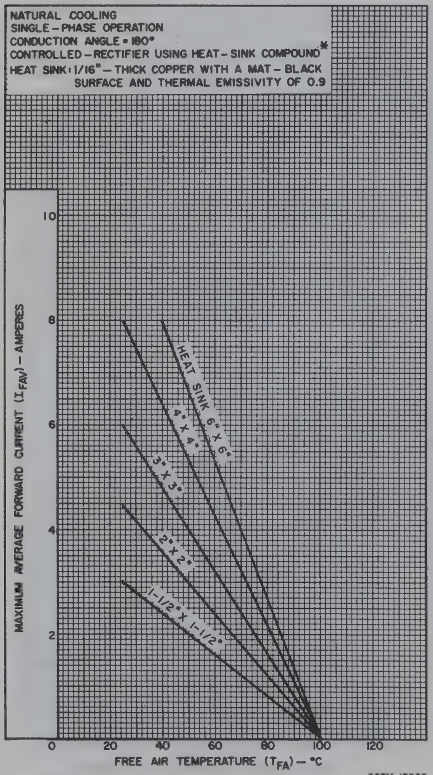
FORWARD CHARACTERISTICS



92CS-12931

Fig. 11

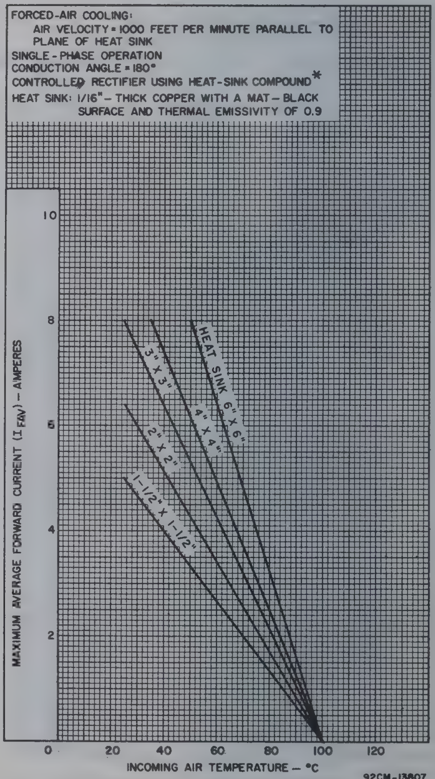
NATURAL-AIR COOLING OPERATION GUIDANCE CHART



92CM-13806

Fig. 12

FORCED-AIR COOLING OPERATION GUIDANCE CHART



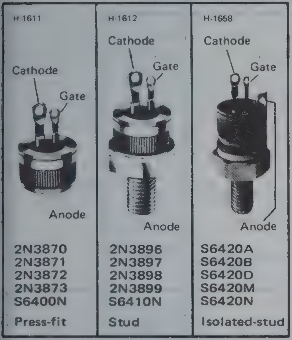
92CM-13807

Fig. 13

*Dow Corning 340 Silicon Heat Sink Compound, or Equivalent.

RCA
Solid State Division

Thyristors
2N3870-2N3873
2N3896-2N3899
S6400 S6410 S6420 Series



35-A Silicon Controlled Rectifiers

Features:

- High di/dt and dv/dt capabilities
- Low on-state voltage at high current levels
- Low thermal resistance
- Shorted-emitter center-gate construction

Voltage Package	100 V Types	200 V Types	400 V Types	600 V Types	800 V Types
Press-Fit (S6400 Series)	2N3870	2N3871	2N3872	2N3873	S6400N (40937)
Stud (S6410 Series)	2N3896	2N3897	2N3898	2N3899	S6410N (40938)
Isolated-Stud (S6420 Series)	S6420A (40680)	S6420B (40681)	S6420D (40682)	S6420M (40683)	S6420N (40952)

Numbers in parentheses (e.g., 40937) are former RCA type numbers.

These RCA types are all-diffused, silicon controlled rectifiers (reverse-blocking triode thyristors) designed for power switching, power control, and voltage regulator applications and for heating, lighting, and motor speed-control circuits.

MAXIMUM RATINGS, *Absolute-Maximum Values:*		2N3870 2N3896 S6420A	2N3871 2N3897 S6420B	2N3872 2N3898 S6420D	2N3873 2N3899 S6420M	S6400N S6410N S6420N	
*NON-REPETITIVE PEAK REVERSE VOLTAGE▲							
Gate Open	V_{RSOM}	150	330	660	700	900	V
NON-REPETITIVE PEAK OFF-STATE VOLTAGE▲							
Gate Open	V_{DSOM}	150	330	660	700	900	V
*REPETITIVE PEAK REVERSE VOLTAGE▲							
Gate Open	V_{RROM}	100	200	400	600	800	V
*REPETITIVE PEAK OFF-STATE VOLTAGE▲							
Gate Open	V_{DROM}	100	200	400	600	800	V
ON-STATE CURRENT:							
$T_C = 65°C$◆, conduction angle = 180°:							
RMS	$I_{T(RMS)}$	35					A
* Average	$I_{T(AV)}$	22					A
For other conditions		See Figs. 3 & 5					
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}						
For one full cycle of applied principal voltage, $T_C = 65°C$							
* 60 Hz (sinusoidal)		350					A
50 Hz (sinusoidal)		300					A
For more than one full cycle of applied principal voltage		See Fig. 5					
RATE OF CHANGE OF ON-STATE CURRENT							
$V_D = V_{DROM}$, $I_{GT} = 200$ mA, $t_r = 0.5$ μs (See Fig. 13)	di/dt	200					A/μs
FUSING CURRENT (for SCR protection):							
$T_J = -40$ to 100°C, t = 1 to 8.3 ms	I^2t	300					A^2s
GATE POWER DISSIPATION●:							
Peak Forward (for 10 μs max., See Fig. 8)	P_{GM}	40					W
Peak Reverse	P_{RGM}	See Fig. 9					
Average (averaging time = 10 ms max.)	$P_{G(AV)}$	0.5					W
*TEMPERATURE RANGE■:							
Storage	T_{stg}	-40 to 125					°C
Operating (Case)	T_C	-40 to 100					°C
TERMINAL TEMPERATURE (During soldering):	T_T						
For 10 s max. (terminals and case)		225					°C

---

* In accordance with JEDEC registration data filed for the JEDEC (2N-series) types.
▲ These values do not apply if there is a positive gate signal. Gate must be open or negatively biased.
◆ $T_C = 60°$ for isolated-stud package types.
● Any product of gate current and gate voltage which results in a gate power less than the maximum is permitted.
■ Temperature measurement point is shown on the DIMENSIONAL OUTLINE.

ELECTRICAL CHARACTERISTICS

At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS			UNITS
		FOR ALL TYPES Unless Otherwise Specified			
		MIN.	TYP.	MAX.	
Peak Off-State Current:					
(Gate open, T_C = 100°C)					
Forward Current (I_{DOM}) at $V_D = V_{DROM}$	I_{DOM}				
Reverse Current (I_{ROM}) at $V_R = V_{RROM}$	or				
2N3870, 2N3896, S6420A		–	0.2	2*	
2N3871, 2N3897, S6420B	I_{ROM}	–	0.25	2.5*	mA
2N3872, 2N3898, S6420D		–	0.3	3*	
2N3873, 2N3899, S6420M, S6400N, S6410N, S6420N		–	0.35	4*	
Instantaneous On-State Voltage:					
i_T = 69 A (peak), T_C = 25°C	v_T	–	–	1.85*	V
i_T = 100 A (peak), T_C = 25°C		–	1.7	2.1	
DC Gate Trigger Voltage:					
V_D = 12 V (dc), R_L = 30 Ω, T_C = -40°C	V_{GT}	–	1.5	3*	V
V_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C		–	1.1	2	
For other case temperatures			See Fig. 11		
DC Gate Trigger Current:					
V_D = 12 V (dc), R_L = 30 Ω, T_C = -40°C		–	46	80*	
V_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C	I_{GT}	1	25	40	mA
For other case temperatures			See Fig. 10		
Instantaneous Holding Current:					
Gate open,					
T_C = 25°C	i_{HO}	0.5	30	70	mA
For other case temperatures			See Fig. 7		
Gate Controlled Turn-On Time: (Delay Time + Rise Time) For $V_D = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.1 μs, I_T = 30 A (peak), T_C = 25°C (See Fig. 12 & 14.)	t_{gt}	–	1.25	2	μs
Circuit Commutated Turn-Off Time: $V_D = V_{DROM}$, i_T = 18 A, pulse duration = 50 μs, dv/dt = 20 V/μs, -di/dt = -30 A/μs, I_{GT} = 200 mA, T_C = 80°C (See Fig. 15.)	t_q	–	20	40	μs
Critical Rate of Rise of Off-State Voltage: $V_D = V_{DROM}$, exponential voltage rise, Gate open, T_C = 100°C (See Fig. 16.)	dv/dt	10	100	–	V/μs
Thermal Resistance, Junction-to-Case:					
Steady-State					
Press-fit & stud types	$R_{\theta JC}$	–	–	0.9*	°C/W
Isolated-stud types		–	–	1	

*In accordance with JEDEC registration data filed for the JEDEC (2N-series) types.

WARNING: The ceramic of the isolated stud package contains beryllium oxide. Do not crush, grind, or abrade this part because the dust resulting from such action may be hazardous if inhaled, Disposal should be by burial.

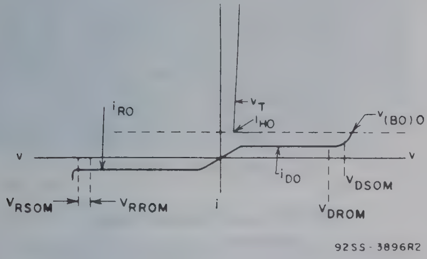

i_{RO}
v_T
i_{HO}
$v_{(BO)O}$
v
v
i_{DO}
V_{DSOM}
V_{RSOM}
V_{RROM}
i
V_{DROM}
92SS-3896R2

Fig.1—Principal voltage-current characteristic.

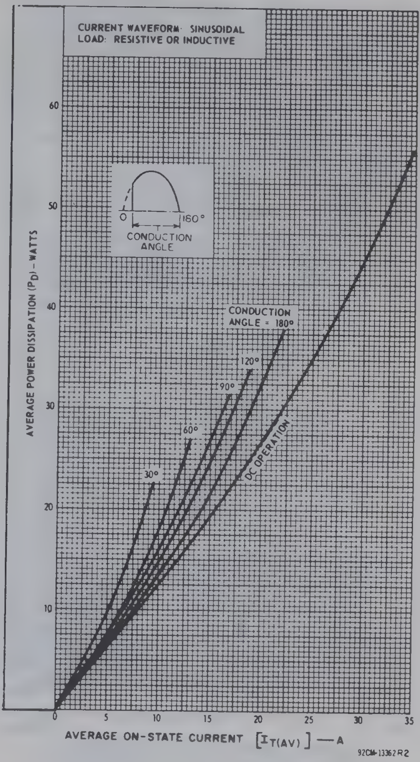


Fig.2—Power dissipation vs. on-state current.

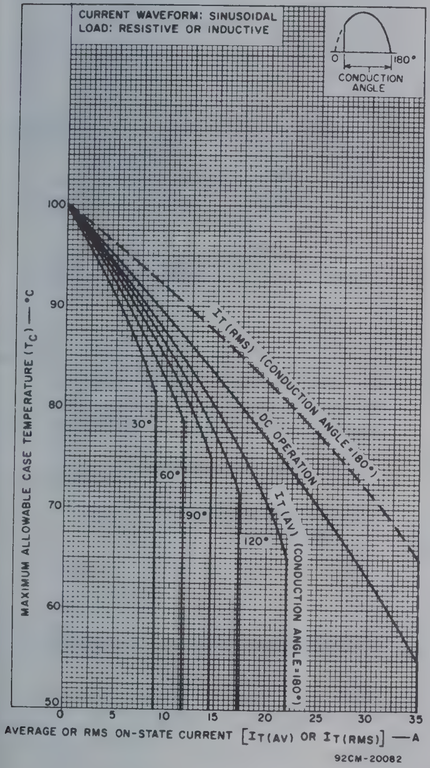


Fig.3—Maximum allowable case temperature vs. on-state current for press-fit and stud types.

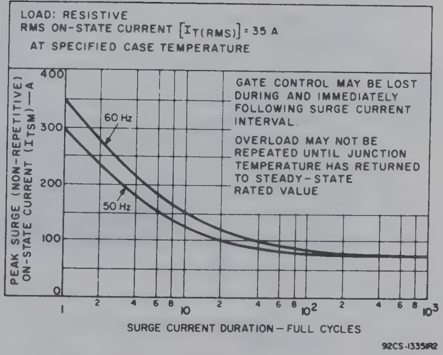


Fig.4 —Peak surge on-state current vs. surge current duration.

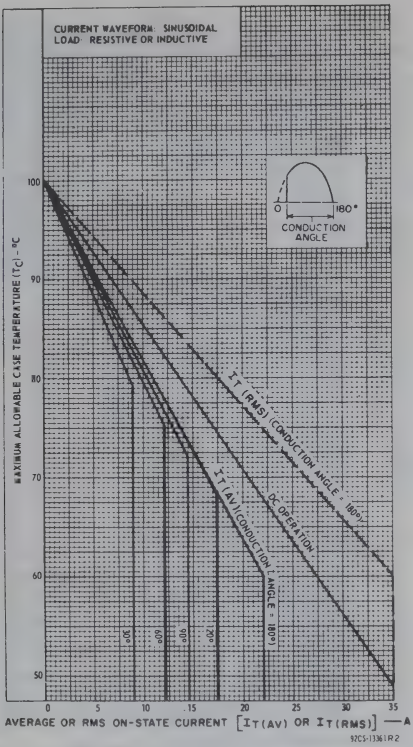


Fig.5—Maximum allowable case temperature vs. on-state current for isolated-stud types.

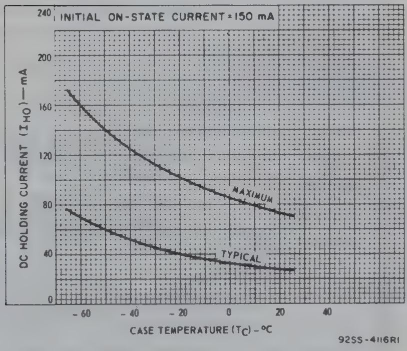


Fig.7—DC holding current vs. case temperature.

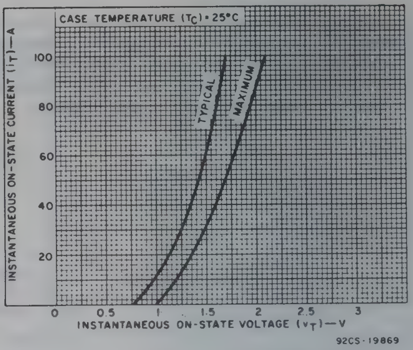


Fig.6—Instantaneous on-state current vs. on-state voltage.

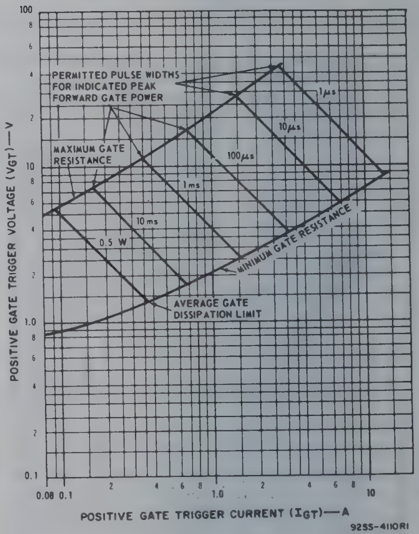


Fig.8—Gate pulse characteristics for forward triggering mode.

TERMINAL CONNECTIONS FOR ALL TYPES

No. 1 — Gate
No. 2 — Cathode
Case, No. 3 — Anode

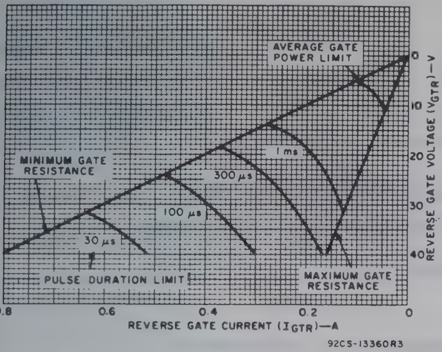


Fig.9—Reverse gate voltage vs. reverse gate current.

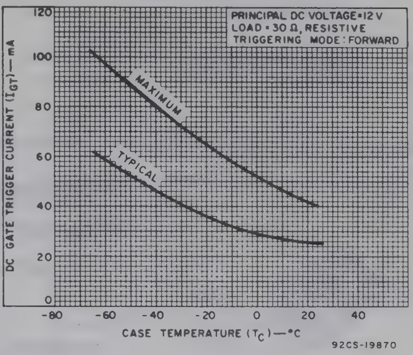


Fig.10—DC gate trigger current (forward) vs. case temperature.

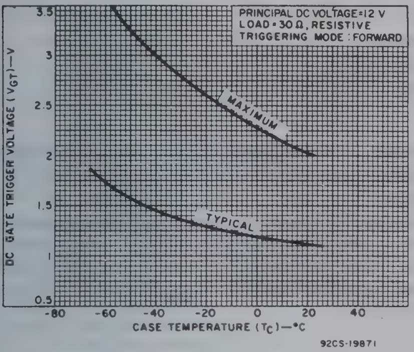


Fig.11—DC gate trigger voltage (forward) vs. case temperature.

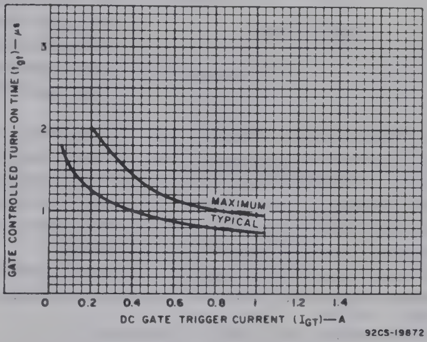


Fig.12—Gate-controlled turn-on time vs. gate trigger current.

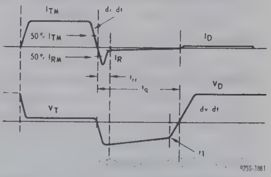
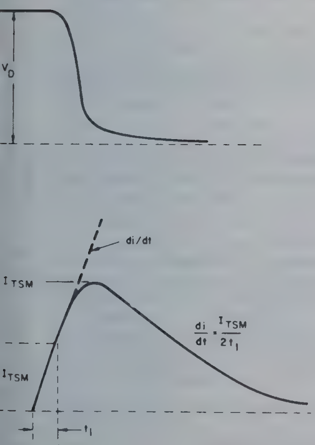

I_{TM}
di dt
50% I_{TM}
50% I_{RM}
I_R
I_D
t_{rr}
t_q
V_D
V_T
dv dt
t1
92SS-3881

Fig. 15—Relationship between instantaneous on-state current and voltage showing reference points for definition of circuit commutated turn-off time (t_q).


V_D
di/dt
I_{TSM}
$\frac{di}{dt} = \frac{I_{TSM}}{2t_1}$
I_{TSM}
t_1
92CS-17063

g.13—Rate of change of on-state current with time (defining di/dt).

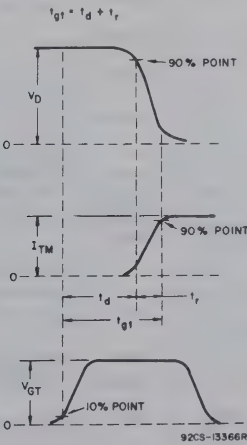

$t_{gt} = t_d + t_r$
90% POINT
V_D
0
I_{TM}
90% POINT
0
t_d
t_r
t_{gt}
V_{GT}
10% POINT
0
92CS-13366R2

Fig.14—Relationship between off-state voltage, on-state current, and gate trigger voltage showing reference points for definition of turn-on time (t_{gt}).

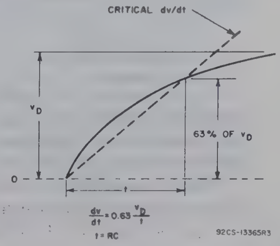
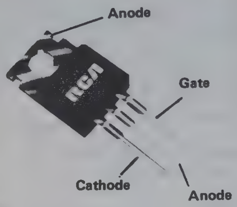

CRITICAL dv/dt
V_D
63% OF V_D
0
t
$\frac{dv}{dt} = 0.63\frac{V_D}{t}$
t = RC
92CS-13365R3

Fig. 16—Rate of rise of off-stage voltage with time (defining critical dv/dt).

Solid State Division

Thyristors

S2060 Series
S2061 Series
S2062 Series



JEDEC TO-220AB

H-1535R1

4-Ampere Sensitive-Gate Silicon Controlled Rectifiers

For Power Switching and Control Applications

Features:

- Microampere gate sensitivity
- Minimum gate current specified for the S2062 series
- 600-V capability
- 4-A (rms) on-state current ratings
- 35-A peak surge capability
- Glass-passivated chip for stability
- Low thermal resistances
- Surge capability curve

The S2060, S2061, and S2062 series● are sensitive-gate silicon controlled rectifiers designed for switching ac and dc currents. These SCR's are divided into the three different series according to gate sensitivity. The types within each series differ in their voltage ratings; the voltage ratings are identified by suffix letters in the type designations.

All types in each series utilize the JEDEC TO-220AB package. Upon request, each type is available in either of two variants of the TO-220AB package. For information on these package variations, contact the RCA Sales Office in your locale.

These thyristors have microampere gate-current requirements which permit operation with low-level logic circuits. They can be used for lighting, power-switching, and motor-speed controls, and for gate-current amplification for driving larger SCR's.

● Formerly the RCA106, RCA107, and RCA108 series.

<table>
<tr><th rowspan="2">MAXIMUM RATINGS, Absolute-Maximum Values:</th><th rowspan="2"></th><th colspan="9">Suffix Letter</th><th rowspan="2"></th></tr>
<tr><th>Q</th><th>Y</th><th>F</th><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th><th>M</th></tr>
<tr><td>NON-REPETITIVE PEAK REVERSE VOLTAGE
R_{GK} = 1000 Ω, T_C = -40 to 110°C</td><td>V_{RSXM}</td><td rowspan="2">25</td><td rowspan="2">50</td><td rowspan="2">75</td><td rowspan="2">125</td><td rowspan="2">250</td><td rowspan="2">400</td><td rowspan="2">500</td><td rowspan="2">600</td><td rowspan="2">700</td><td rowspan="2">V</td></tr>
<tr><td>NON-REPETITIVE PEAK OFF-STATE VOLTAGE
R_{GK} = 1000 Ω, T_C = -40 to 110°C</td><td>V_{DSXM}</td></tr>
<tr><td>REPETITIVE PEAK REVERSE VOLTAGE
R_{GK} = 1000 Ω, T_C = -40 to 110°C</td><td>V_{RRXM}</td><td rowspan="2">15</td><td rowspan="2">30</td><td rowspan="2">50</td><td rowspan="2">100</td><td rowspan="2">200</td><td rowspan="2">300</td><td rowspan="2">400</td><td rowspan="2">500</td><td rowspan="2">600</td><td rowspan="2">V</td></tr>
<tr><td>REPETITIVE PEAK OFF-STATE VOLTAGE
R_{GK} = 1000 Ω, T_C = -40 to 110°C</td><td>V_{DRXM}</td></tr>
<tr><td>ON-STATE CURRENT:
Conduction angle = 180°, T_C = 85°C</td><td></td><td colspan="9"></td><td></td></tr>
<tr><td>Average ac value</td><td>$I_{T(AV)}$</td><td colspan="9">2.5</td><td>A</td></tr>
<tr><td>RMS value</td><td>$I_{T(RMS)}$</td><td colspan="9">4</td><td>A</td></tr>
<tr><td>DC operation</td><td>$I_{T(DC)}$</td><td colspan="9">2.75</td><td>A</td></tr>
<tr><td>PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:
For one cycle of applied principal voltage, T_C = 85°C</td><td>I_{TSM}</td><td colspan="9"></td><td></td></tr>
<tr><td>60 Hz (sinusoidal)</td><td></td><td colspan="9">35</td><td>A</td></tr>
<tr><td>50 Hz (sinusoidal)</td><td></td><td colspan="9">28</td><td>A</td></tr>
<tr><td>60 Hz (sinusoidal)</td><td>I_{TSM}</td><td colspan="9">35</td><td>A</td></tr>
<tr><td>For more than one cycle of applied principal voltage</td><td></td><td colspan="9">See Fig. 6</td><td></td></tr>
<tr><td>PEAK GATE CURRENT (t = 10 µsec)</td><td>I_{GFM}</td><td colspan="9">0.2</td><td>A</td></tr>
<tr><td>PEAK GATE REVERSE VOLTAGE</td><td>V_{GRM}</td><td colspan="9">6</td><td>V</td></tr>
<tr><td>RATE OF CHANGE OF ON-STATE CURRENT:
$V_{DM} = V_{DROM}$, I_{GT} = 1 mA, t_r = 0.5 µs, T_C = 110°C</td><td>di/dt</td><td colspan="9">100</td><td>A/µ</td></tr>
<tr><td>FUSING CURRENT (for SCR protection):
T_J = −40 to 110°C, t = 1 to 8.3 ms</td><td>I^2t</td><td colspan="9">2.6</td><td>A^2</td></tr>
</table>

MAXIMUM RATINGS, *Absolute-Maximum Values (Cont'd.)*:

		Suffix Letter Q Y F A B C D E M	
GATE POWER DISSIPATION:			
PEAK FORWARD (for 10 μs max.)	P_{GM}	0.5	W
AVERAGE (averaging time = 10 ms max.)	$P_{G(AV)}$	0.1	W
TEMPERATURE RANGE:			
Storage	T_{stg}	-40 to +150	°C
Operating (case)*	T_C	-40 to +110	°C
TERMINAL TEMPERATURE (During soldering):			
For 10 s max.	T_T	250	°C

*Temperature measuring point is shown in the dimensional outline.

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS FOR ALL TYPES UNLESS OTHERWISE SPECIFIED			UNITS
		MIN.	TYP.	MAX.	
PEAK OFF-STATE CURRENT:					
Forward, $V_D = V_{DRXM}$, $R_{GK} = 1000\ \Omega$	I_{DRXM}				μA
$T_C = 25^oC$		–	0.1	10	
$T_C = 110^oC$		–	10	100	
Reverse, $V_R = V_{RRXM}$, $R_{GK} = 1000\ \Omega$	I_{RRXM}				
$T_C = 25^oC$		–	0.1	10	
$T_C = 100^oC$		–	10	100	
INSTANTANEOUS ON-STATE VOLTAGE:					
For $i_T = 4$ A and $T_C = 25^oC$ (See Fig. 16)	v_T	–	1.25	2.2	V
DC GATE TRIGGER CURRENT:					
$V_D = 12$ V (dc), $R_L = 30\ \Omega$, $T_C = 25^oC$:	I_{GT}				μA
S2060 Series		–	–	200	
S2061 Series		–	–	500	
S2062 Series		100	–	2000	
For other case temperatures		See Figs. 10,11,12			
DC GATE TRIGGER VOLTAGE:					
$V_D = 12$ V (dc), $R_L = 30\ \Omega$, $T_C = 25^oC$	V_{GT}	–	0.5	0.8	V
For other case temperatures		See Fig. 14			
INSTANTANEOUS HOLDING CURRENT:					
$R_{GK} = 1000\ \Omega$, $V_D = 12$ V, $I_{T\ (INITIAL)} = 50$ mA, $T_C = 25^oC$:	i_H				mA
S2060 Series		–	1.7	3	
S2061 Series		–	3.9	6	
S2062 Series		–	6	10	
LATCHING CURRENT:					
$R_{GK} = 1000\ \Omega$, $V_D = 12$ V, $T_C = 25^oC$:	i_L				mA
S2060 Series ($I_{GT} = 200\ \mu$A)		–	1.8	4	
S2061 Series ($I_{GT} = 500\ \mu$A)		–	2.5	8	
S2062 Series ($I_{GT} = 2000\ \mu$A)		–	8	12	
CRITICAL RATE OF RISE OF OFF-STATE VOLTAGE: $V_D = V_{DRXM}$, $R_{GK} = 1000\ \Omega$, Exponential rise, $T_C = 110^oC$	dv/dt	5	8	–	V/μs
GATE-CONTROLLED TURN-ON TIME: $V_D = V_{DRXM}$, $i_T = 1$ A, $R_{GK} = 1000\ \Omega$, $I_{GT} = 1$ mA, rise time = 0.1 μs, $T_C = 25^oC$	t_{gt}	–	1.7	2.5	μs
CIRCUIT COMMUTATED TURN-OFF TIME: $V_D = V_{DRXM}$, $i_T = 1$ A, $R_{GK} = 1000\ \Omega$, Pulse Duration = 50 μs, dv/dt = 5 V/μs, di/dt = –10 A/μs, $I_{GT} = 1$ mA at turn on, $T_C = 110^oC$	t_q	–	30	100	μs
THERMAL RESISTANCE:					
Junction-to-Case*	$R_{\theta JC}$	–	–	3.5	$^oC/W$
Junction-to-Ambient	$R_{\theta JA}$	–	–	60	

* Temperature measuring point is shown in the dimensional outline.

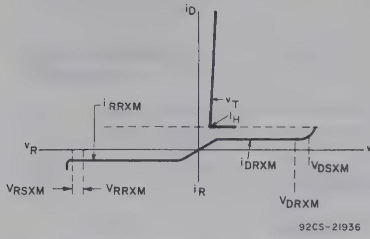


Fig. 1—Typical volt-ampere characteristics for all series.

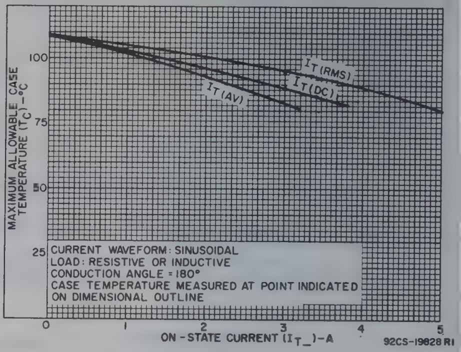


Fig. 2—Maximum allowable case temperature vs. on-state-current for all series.

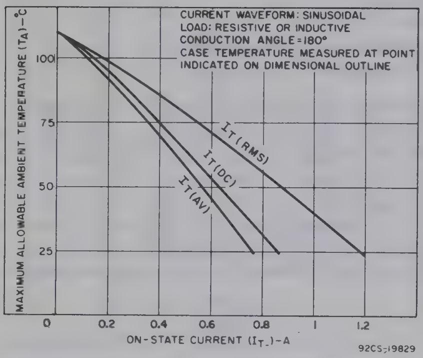


Fig. 3—Maximum allowable ambient temperature vs. on-state current for all series.

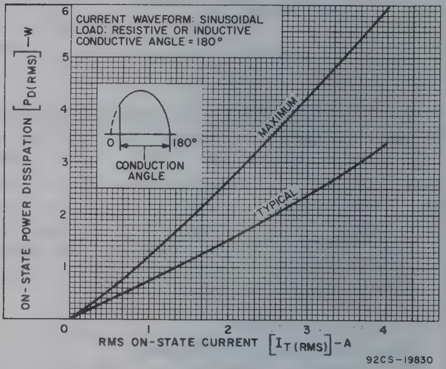


Fig. 4—Power dissipation vs. rms-on-state current for all series.

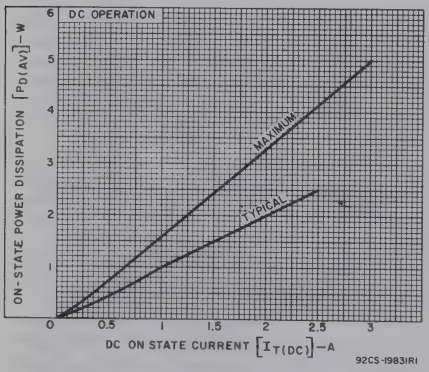


Fig. 5—Power dissipation vs. dc on-state current for all series.

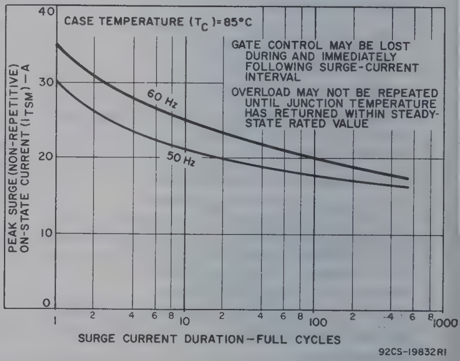


Fig. 6—Peak surge on-state current vs. surge-current duration for all series.

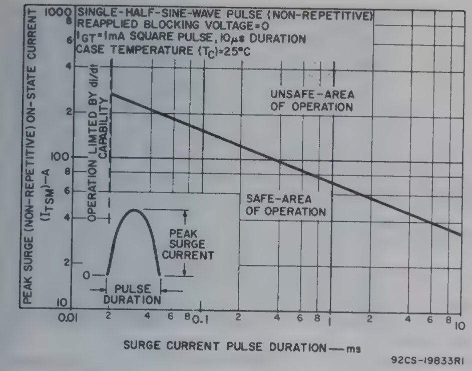


Fig. 7—Surge capability without reapplied blocking voltage for all series.

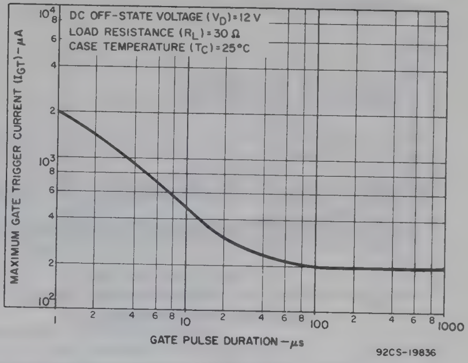


Fig. 8—Maximum gate trigger current vs. gate pulse duration for types in the S2060 series.

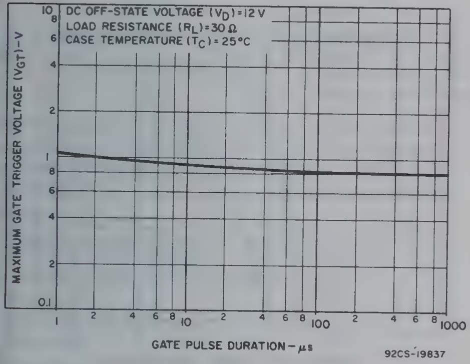


Fig. 9—Maximum gate trigger voltage vs. gate pulse duration for types in the S2060 series.

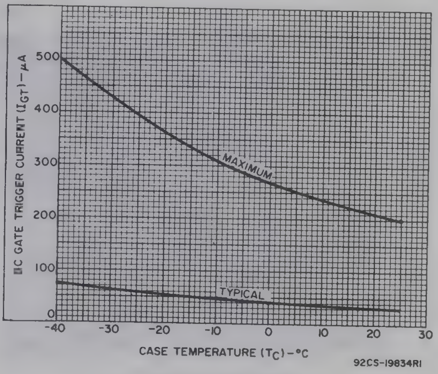


Fig. 10—DC gate trigger current vs. case temperature for S2060 series.

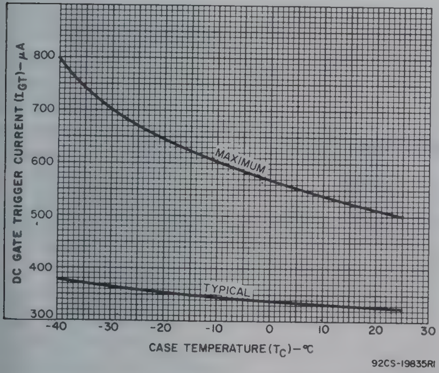


Fig. 11—DC gate trigger current vs. case temperature for S2061 series.

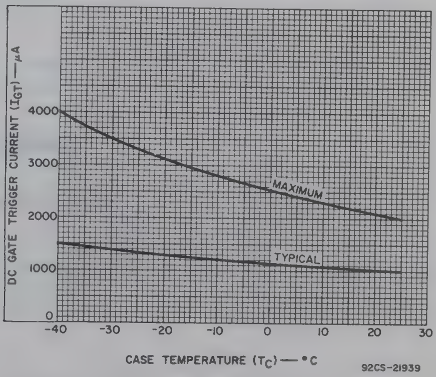


Fig. 12—DC gate trigger current vs. case temperature for S2062 series.

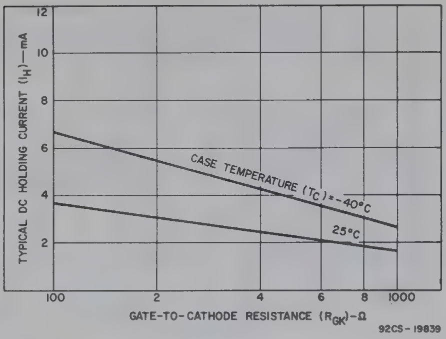


Fig. 13—DC holding current vs. gate-cathode resistance for the S2060 series.

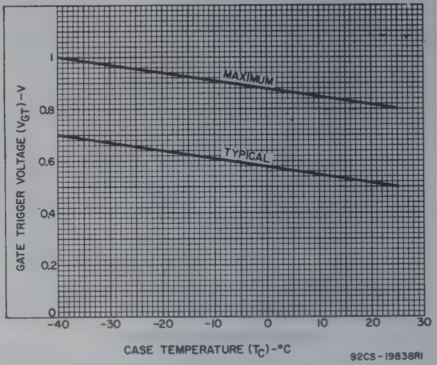


Fig. 14—Gate trigger voltage vs. case temperature for all series.

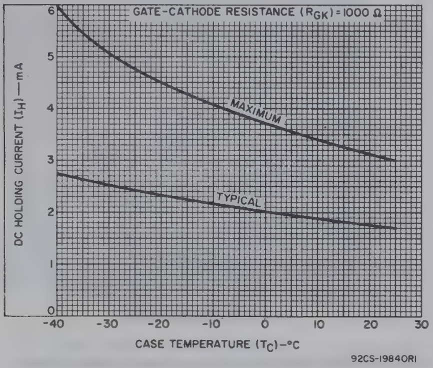


Fig. 15—DC holding current vs. case temperature for the S2060 series.

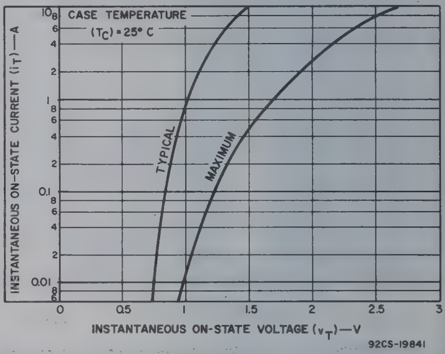


Fig. 16—Instantaneous on-state current vs. on-state voltage for al series.

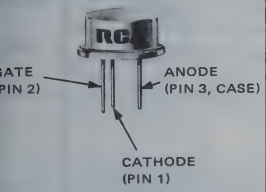
TERMINAL CONNECTIONS

No. 1 — Cathode
Mounting Flange, No. 2 — Anode
No. 3 — Gate

Solid State
Division

Thyristors

S2400 Series



EDEC TO-8

4.5-A Silicon Controlled Rectifiers For Capacitive-Discharge Systems

Features:

- 200-A surge current capability
- Low switching losses
- High di/dt and dv/dt capabilities
- Shorted-emitter gate-cathode construction
- Forward and reverse gate-dissipation ratings
- Low forward voltage drop at high current levels

Voltage / Package	100 V Type	200 V Type	400 V Type	600 V Type
TO-66	S2400A (40942)	S2400B (40943)	S2400D (40944)	S2400M (40945)

Numbers in parentheses are former RCA type numbers.

nese RCA types are all-diffused silicon controlled rectifiers everse-blocking triode thyristors) designed for high-peak-irrent low-average-current applications. Typical applications e ignition service, crowbars, and other capacitive-discharge stems.

These SCR's have an rms on-state current rating ($I_{T\,[RMS]}$) of 4.5 amperes and have voltage ratings (V_{DROM}) of 100, 200, 400, and 600 volts.

XIMUM RATINGS, *Absolute-Maximum Values:*

		S2400A	S2400B	S2400D	S2400M	
n-repetitive peak reverse voltage▲						
Gate open	V_{RSOM}	150	250	500	700	V
n-repetitive peak forward voltage▲						
Gate open	V_{DSOM}	150	250	500	700	V
petitive peak reverse voltage▲						
Gate open	V_{RROM}	100	200	400	600	V
petitive peak off-state voltage▲						
Gate open	V_{DROM}	100	200	400	600	V
-state current:						
T_C = 75°C, conduction angle = 180°						
RMS	$I_{T(RMS)}$	4.5				A
Average	$I_{T(AV)}$	3.3				A
For other conditions		See Fig.3				
k surge (non-repetitive) on-state current:	I_{TSM}					
For one cycle of applied principal voltage, T_C = 75°C						
50-Hz, sinusoidal		170				A
60-Hz, sinusoidal		200				A
For more than one full cycle of applied principal voltage		See Fig.4				
te of change of on-state current						
$V_D = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.5 μs (See Fig.12)	di/dt	200				A/μs
sing current (for SCR protection):						
T_J = −40 to 100°C, t = 1.5 to 10 ms	I^2t	150				A^2s
te power dissipation:●						
Peak forward (for 1 μs max.)	P_{GM}	40				W
Peak reverse	P_{RGM}	See Fig.8				
Average (averaging time = 10 ms, max.)	$P_{G(AV)}$	0.5				W

MAXIMUM RATINGS, *Absolute-Maximum Values (Cont'd.):*

		S2400A	S2400B	S2400D	S2400M
Temperature range:■					
Storage	T_{stg}	–40 to 150			
Operating (case)	T_C	–40 to 100			
Pin temperature (during soldering):	T_P				
For 10 s max. (pins and case)		225			

▲ These values do not apply if there is a positive gate signal. Gate must be open or negatively biased.

● Any product of gate current and gate voltage which results in a gate power less than the maximum is permitted.

■ Temperature measurement point is shown on the DIMENSIONAL OUTLINE.

ELECTRICAL CHARACTERISTICS, At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C

CHARACTERISTIC	SYMBOL	LIMITS For All Types Min.	LIMITS For All Types Typ.	LIMITS For All Types Max.	UNI
Peak Off-State Current: (Gate open, T_C = 100°C) Forward at V_D = V_{DROM}	I_{DOM}	–	0.2	3	m
Reverse at V_R = V_{RROM}	I_{ROM}	–	0.1	2	
Instantaneous On-State Voltage: i_T = 100 A, T_C = 25°C, See Fig.5	v_T	–	2.5	3	
DC Gate Trigger Voltage: V_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C For other conditions	V_{GT}	–	1.1 See Fig.10	2	
DC Gate Trigger Current: V_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C For other conditions	I_{GT}	–	8 See Fig.9	15	m
DC Holding Current: Gate open, initial principal current = 150 mA, T_C = 25°C For other conditions	I_{HO}	–	9 See Fig.6	20	m
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) V_D = V_{DROM}, I_{GT} = 200 mA, t_r = 0.1 μs, i_T = 30 A (peak), T_C = 25°C (See Fig.11)	t_{gt}	–	1.6	2.5	μ
Circuit-Commutated Turn-Off Time: V_D = V_{DROM}, i_T = 18 A, pulse duration = 50 μs, dv/dt = 20 V/μs, di/dt = –30 A/μs, I_{GT} = 200 mA, T_C = 75°C See Fig.14	t_q	–	20	40	μ
Critical Rate of Rise of Off-State Voltage: V_D = V_{DROM}, exponential voltage rise, gate open, T_C = 100°C, See Fig.15	dv/dt	10	100	–	V/μ
Thermal Resistance: Steady-state Junction-to-case	$R_{\theta JC}$	–	–	5	°C/
Junction-to-ambient	$R_{\theta JA}$	–	–	40	

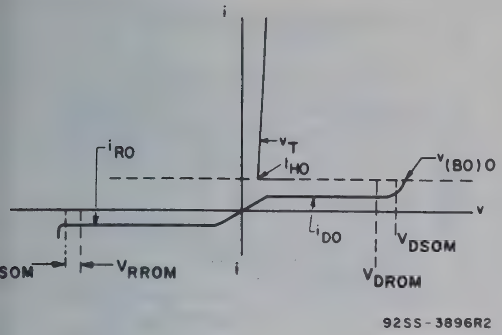

i
v_T
i_{RO}
i_{HO}
$v_{(BO)O}$
v
i_{DO}
V_{DSOM}
SOM
V_{RROM}
i
V_{DROM}
92SS-3896R2

Fig. 1—Principal voltage-current characteristics.

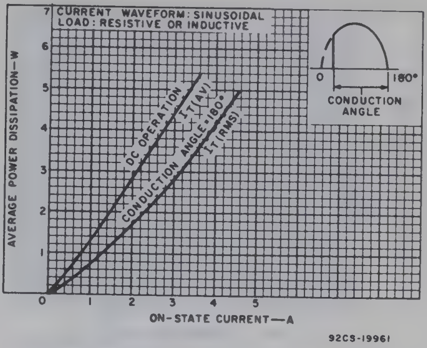


Fig. 2—Power dissipation vs. on-state current.

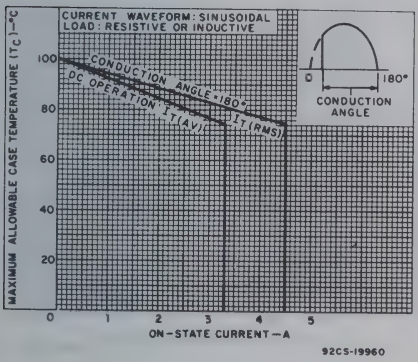


Fig. 3—Maximum allowable case temperature vs. on-state current.

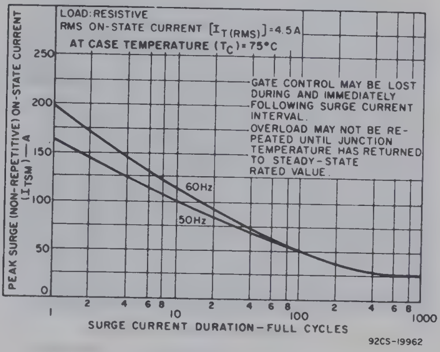


Fig. 4—Peak surge on-state current vs. surge current duration.

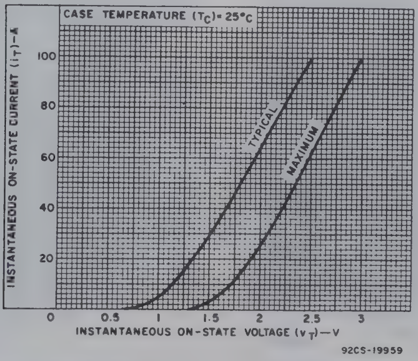


Fig. 5—Instantaneous on-state current vs. on-state voltage.

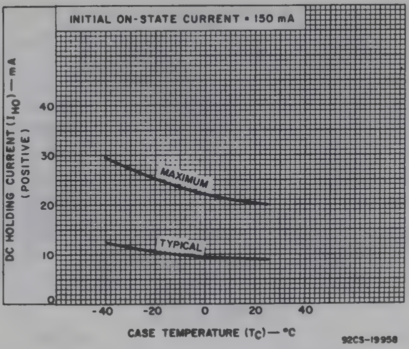


Fig. 6—DC holding current vs. case temperature.

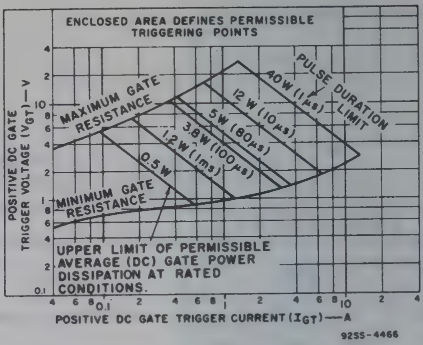


Fig. 7—Gate pulse characteristics for forward triggering mode.

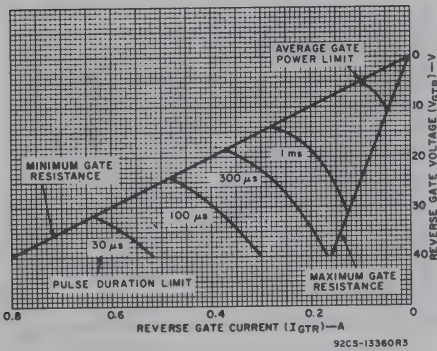


Fig. 8—Reverse gate voltage vs. reverse gate current.

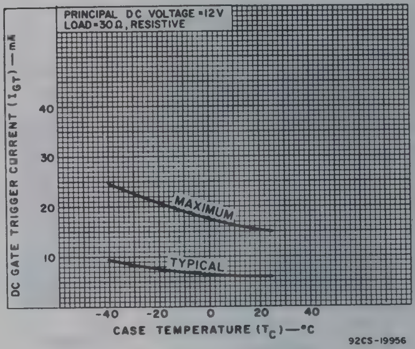


Fig. 9—DC gate-trigger current (forward) vs. case temperature.

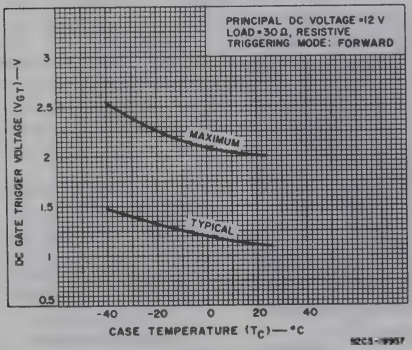


Fig. 10—DC gate-trigger voltage (forward) vs. case temperature.

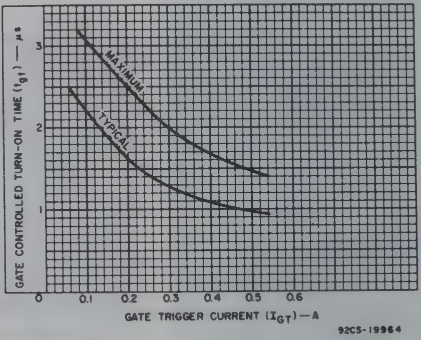


Fig. 11—Gate-controlled turn-on time vs. gate-trigger current.

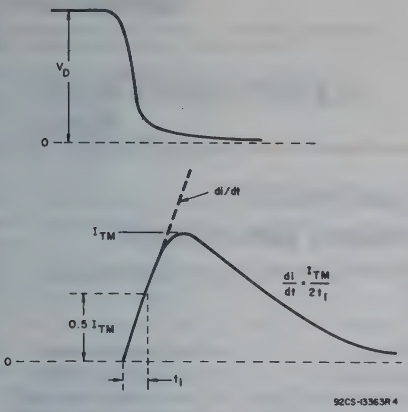

VD
0
di/dt
ITM
di/dt = ITM/2t1
0.5 ITM
0
t1
92CS-13363R4

Fig. 12—Rate of change of on-state current with time (defining di/dt).

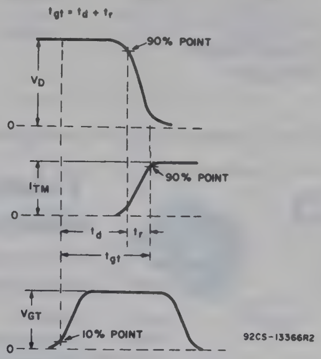

tgt = td + tr
90% POINT
VD
0
ITM
90% POINT
0
td
tr
tgt
VGT
10% POINT
0
92CS-13366R2

Fig. 13—Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).

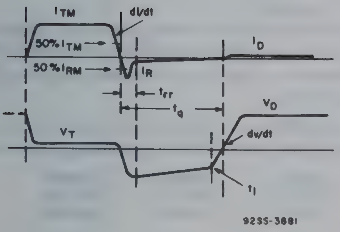

ITM
dv/dt
50% ITM
ID
50% IRM
IR
trr
tq
VD
VT
dv/dt
t1
92SS-3881

Fig. 14—Relationship between instantaneous on-state current and voltage showing reference points for definition of circuit-commutated turn-off time (t_q).

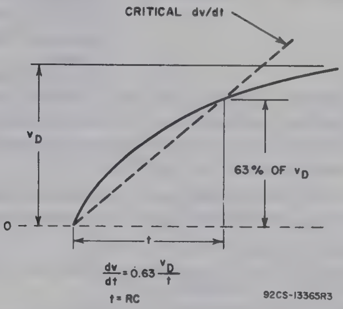

CRITICAL dv/dt
VD
63% OF VD
0
t
dv/dt = 0.63 VD/t
t = RC
92CS-13365R3

Fig. 15—Rate of rise of off-state voltage with time (defining criitcal dv/dt).

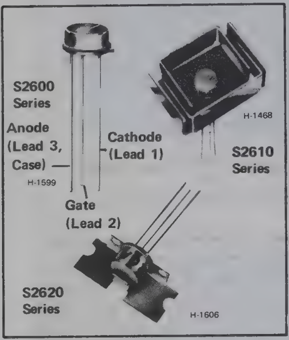
TERMINAL CONNECTIONS

Pin 1 — Cathode
Pin 2 — Gate
Case, Pin 3 — Anode

Solid State Division

Thyristors

S2600 S2610 S2620 Series



7-Ampere "Low-Profile" Silicon Controlled Rectifiers

For Power Switching, Power Control, Power Crowbar, and Ignition Applications

Features:

- Forward and reverse gate ratings
- All-diffused center gate construction
- Low leakage currents, both forward and reverse
- Low forward voltage drop at high current levels
- High pulse-current capability for capacitor-discharge ignition circuits
- High dv/dt capability
- Low switching losses
- Low thermal resistance
- Sub-cycle surge capability cur

Package \ Voltage	200 V Types	400 V Types	600 V Types
"Low-Profile", TO-5	S2600B (40654)	S2600D (40655)	S2600M (40833)
"Low-Profile", TO-5 w/radiator	S2610B (40658)	S2610D (40659)	S2610M (40835)
"Low-Profile", TO-5 w/heat spreader	S2620B (40656)	S2620D (40657)	S2620M (40834)

Numbers in parentheses are former RCA type numbers.

The S2600, S2610, and S2620 series are all-diffused, silicon controlled rectifiers (reverse-blocking triode thyristors) for capacitor-discharge ignition systems, high-voltage generators, and power-switching and control applications.

S2600B, S2600D, and S2600M have a three-lead low-profile package (similar to the JEDEC TO-5). They may be used in capacitor-discharge ignition systems (battery or magneto types) for internal combustion engines, electronic igniters, and high-voltage generators. Other uses are power-control and power-switching circuits.

S2610B, S2610D, and S2610M have integral heat radiators; S2620B, S2620D, and S2620M have integral heat spreaders.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		S2600B S2610B S2620B	S2600D S2610D S2620D	S2600M S2610M S2620M	
NON-REPETITIVE PEAK REVERSE VOLTAGE•					
Gate open	V_{RSOM}	250	500	700	V
NON-REPETITIVE PEAK FORWARD VOLTAGE•					
Gate open	V_{DSOM}	250	500	700	V
REPETITIVE PEAK REVERSE VOLTAGE•					
Gate open	V_{RROM}	200	400	600	V
REPETITIVE PEAK OFF-STATE VOLTAGE•					
Gate open	V_{DROM}	200	400	600	V
RMS ON-STATE CURRENT (Conduction angle = 180°)	$I_{T(RMS)}$		See Figs. 7-11		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}				
For one cycle of applied principal voltage					
60 Hz (sinusoidal)		100	100	100	A
50 Hz (sinusoidal)		85	85	85	A
For more than one cycle of applied principal voltage			See Fig. 12		
PEAK REPETITIVE ON-STATE CURRENT† (See Fig. 21):	I_{TRM}				
Duty factor = 0.1%, T_C = 75°C Pulse duration = 5 µs (min.), 20 µs (max.)		100	100	100	A
RATE OF CHANGE OF ON-STATE CURRENT:					
$V_{DM} = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.5 µs (See Fig. 1)	di/dt		200		A/µs
FUSING CURRENT (for SCR protection):					
T_J = −65 to 100°C, t = 1 to 8.3 ms	I^2t		40		A^2s

Continued on next page.

AXIMUM RATINGS, (Cont'd).

For Operation with Sinusoidal Supply Voltage at Frequencies up to 0/60 Hz and with Resistive or Inductive Load.

		S2600B S2610B S2620B	S2600D S2610D S2620D	S2600M S2610M S2620M	
ON-REPETITIVE SUB-CYCLE SURGE CURRENT:					
T_C = 25°C, single pulse, I_{GT} = 50 mA, 10 μs square pulse			See Fig. 20		
ATE POWER DISSIPATION▲:					
PEAK FORWARD (for 1 μs max.)	P_{GM}	40	40	40	W
PEAK REVERSE	P_{RGM}		See Fig. 14		
AVERAGE (averaging time = 10 ms, max.)	$P_{G(AV)}$	0.5	0.5	0.5	W
EMPERATURE RANGE♦:					
Storage	T_{stg}		-65 to +150		°C
Operating (case)	T_C		-65 to +100		°C
EAD TEMPERATURE (During soldering)■:					
For 10 s max. for case or leads			225		°C

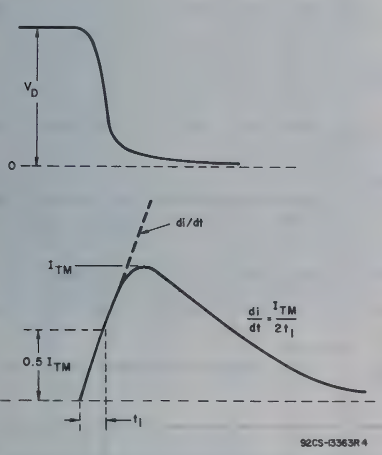
When rms current exceeds 4 amperes (maximum rating for the anode lead), connection must be made to the case.

These values do not apply if there is a positive gate signal. Gate must be open, terminated, or have negative bias.

Any values of peak gate current or peak gate voltage that yield the maximum gate power are permissible.

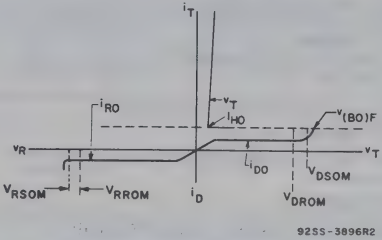
For information on the reference point of temperature measurement, see dimensional outlines.

When these devices are soldered directly to the heat sink, a 60/40 solder should be used. Case heating time should be a minimum . . . sufficient to allow the solder to flow freely.



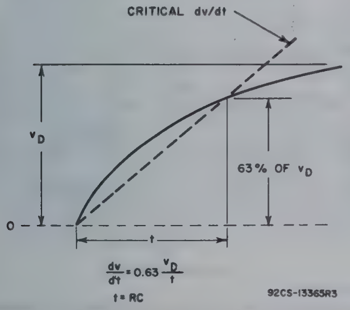
V_D
0
di/dt
I_{TM}
$\frac{di}{dt} = \frac{I_{TM}}{2t_1}$
0.5 I_{TM}
0
t_1
92CS-13363R4

ig. 1—Rate of change of on-state current with time (defining di/dt).



i_T
i_{RO}
v_T
I_{HO}
$v_{(BO)F}$
v_R
v_T
i_{DO}
V_{DSOM}
V_{RSOM}
V_{RROM}
i_D
V_{DROM}
92SS-3896R2

Fig. 2—Principal voltage-current characteristics.



CRITICAL dv/dt
v_D
63% OF v_D
0
t
$\frac{dv}{dt} = 0.63\frac{v_D}{t}$
t = RC
92CS-13365R3

ig. 3—Oscilloscope display of critical rate of rise of off-state voltage (critical dv/dt).

TERMINAL CONNECTIONS

S2600 SERIES

Lead 1 — Cathode
Lead 2 — Gate
Case, Lead 3 — Anode

S2610 SERIES

Lead 1 — Cathode
Lead 2 — Gate
Heat Radiator, Lead 3 — Anode

S2620 SERIES

Lead 1 — Cathode
Lead 2 — Gate
Heat Spreader, Lead 3 — Anode

ELECTRICAL CHARACTERISTICS, *At maximum ratings and at indicated case temperature (T_C) unless otherwise specified*

CHARACTERISTIC	SYMBOL	LIMITS						UNITS
		S2600 Series			S2610 Series S2620 Series			
		MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	
PEAK OFF-STATE CURRENT: (Gate Open, T_C = +100°C) FORWARD, $V_D = V_{DROM}$	I_{DOM}	–	0.1	0.5	–	0.2	1.5	mA
REVERSE, $V_R = V_{RROM}$	I_{ROM}	–	0.05	0.5	–	0.1	1.5	
INSTANTANEOUS ON-STATE VOLTAGE: For i_T = 30 A and T_C = +25°C	v_T	–	1.9	2.6	–	1.9	2.6	V
DC GATE TRIGGER CURRENT: V_D = 12 V (DC) R_L = 30 Ω T_C = +25°C	I_{GT}	–	6	15	–	6	15	mA
For other case temperatures		See Fig. 16						
DC GATE TRIGGER VOLTAGE: V_D = 12 V (DC) R_L = 30 Ω T_C = +25°C	V_{GT}	–	0.65	1.5	–	0.65	1.5	V
For other case temperatures		See Fig. 17						
INSTANTANEOUS HOLDING CURRENT: Gate Open and T_C = +25°C	i_{HO}	–	9	20	–	9	20	mA
For other case temperatures		See Fig. 18						
CRITICAL RATE-OF-RISE OF OFF-STATE VOLTAGE: $V_D = V_{DROM}$ Exponential rise, T_C = +100°C (See Fig. 3)	dv/dt	20	200	–	20	200	–	V/μs
GATE CONTROLLED TURN-ON TIME: $V_D = V_{DROM}$, i_T = 4.5 A I_{GT} = 200 mA, 0.1 μs rise time T_C = +25°C (See Fig. 4)	t_{gt}	–	1	2	1	2	–	μs
CIRCUIT COMMUTATED TURN-OFF TIME: $V_D = V_{DROM}$, i_T = 2 A Pulse Duration = 50 μs dv/dt = 20V/μs, di/dt = -30A/μs I_{GT} = 200 mA at turn on, T_C = +75°C (See Fig. 5)	t_q	–	15	50	–	15	50	μs
THERMAL RESISTANCE: Junction-to-Case	$R_{\theta JC}$	–	–	5	–	–	5	°C/W
Junction-to-Ambient (See dimensional outlines)	$R_{\theta JA}$	–	–	120	–	–	30 (S2610 Series)	
Junction-to-Heat Spreader (See dimensional outline)	$R_{\theta JHS}$	–	–	–	–	–	7 (S2620 Series)	

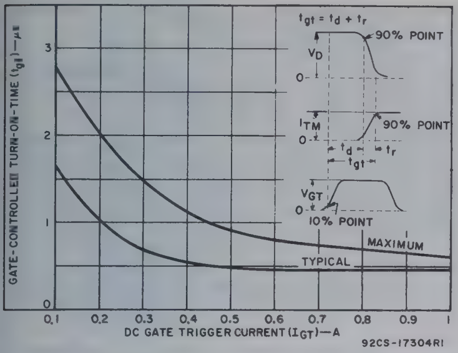


Fig. 4—Gate controlled turn-on time (t_{gt}) vs. gate trigger current.

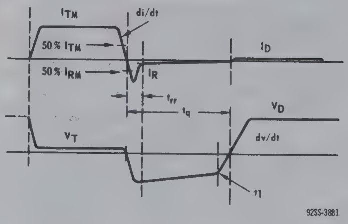

ITM
di/dt
50% ITM
50% IRM
IR
ID
trr
tq
VD
VT
dv/dt
tq
92SS-3881

Fig. 5—Oscilloscope display for measurement of circuit commutated turn-off time (tq).

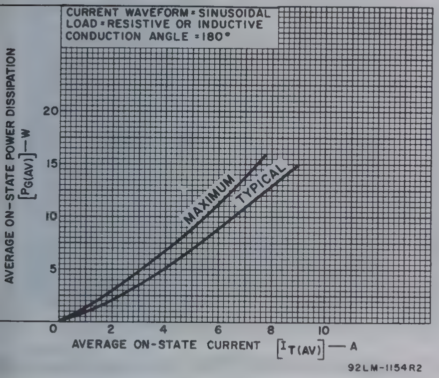


Fig. 6—Power dissipation vs. on-state current.

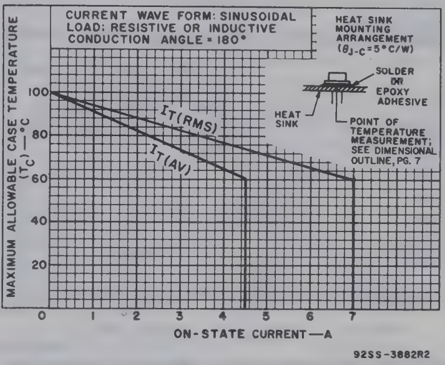
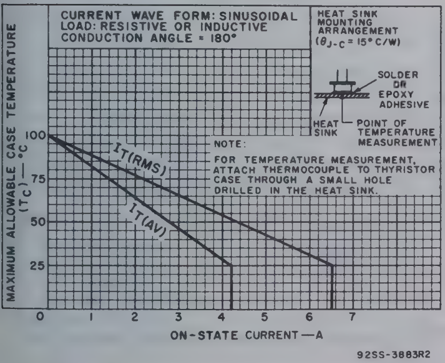


Fig. 7—Maximum allowable case temperature vs. on-state current for S2600 series.



ig. 8—Maximum allowable case temperature vs. on-state current for S2600 series.

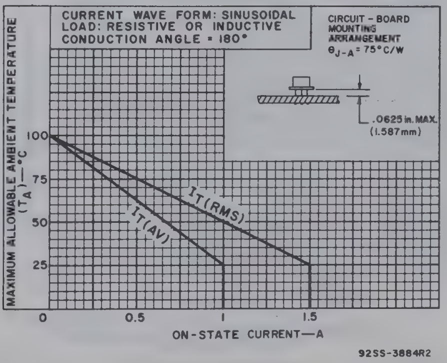
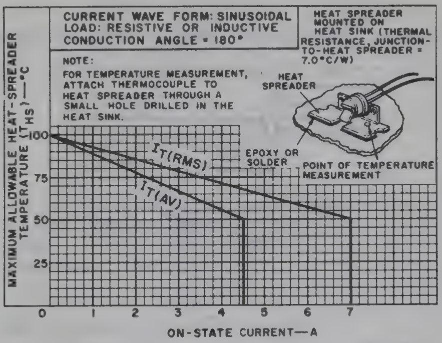
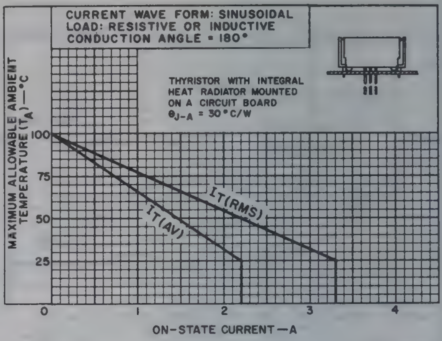


Fig. 9—Maximum allowable ambient temperature vs. on-state current for 2600 series.



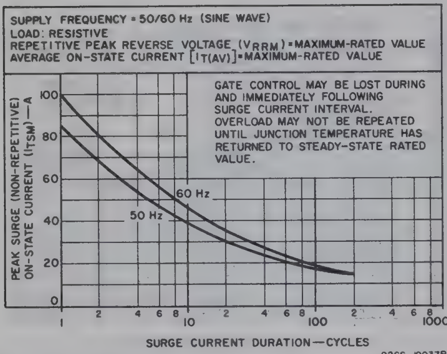
92SS-3885R2

Fig. 10—Maximum allowable heat-speader temperature vs. on-state current for S2620 series.



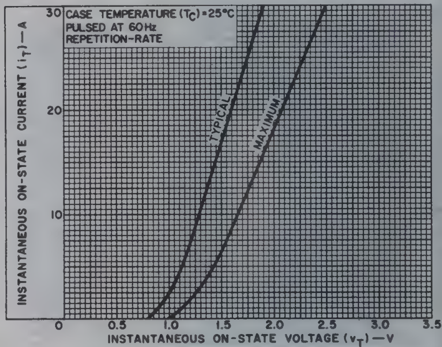
92SS-3886R2

Fig. 11—Maximum allowable ambient temperature vs. on-state current for S2610 series.



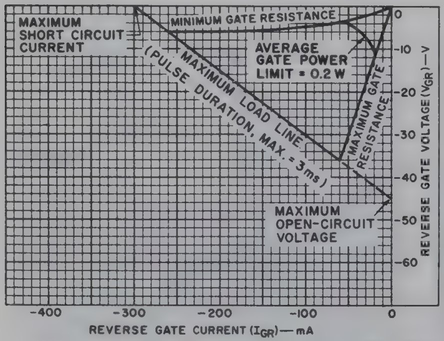
92CS-19037R1

Fig. 12—Peak surge on-state current vs. surge current duration for all types.



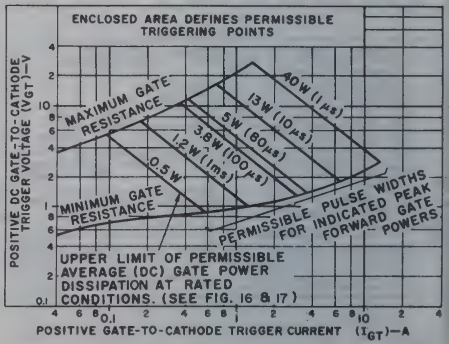
92LS-1150R1

Fig. 13—Instantaneous on-state current vs. on-state voltage for all types.



92SS-3887R1

Fig. 14—Reverse gate voltage vs. reverse gate current.



92SS-3888R1

Fig. 15—Gate pulse characteristics for forward triggering mode.

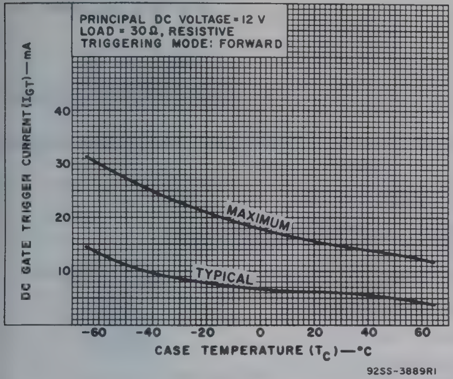


Fig. 16—DC gate-trigger current (forward) vs. case temperature.

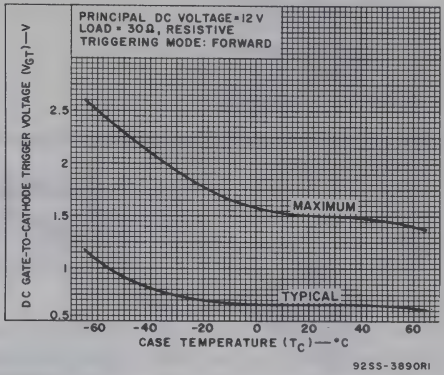


Fig. 17—DC gate-trigger voltage vs. case temperature.

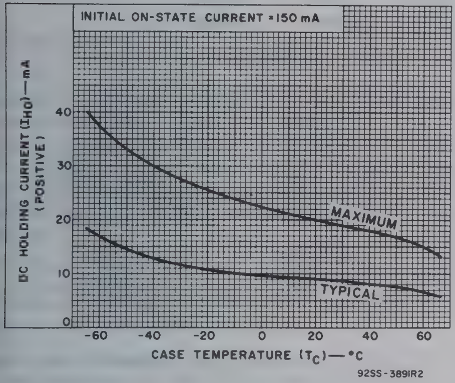


Fig. 18—DC holding current (positive) vs. case temperature.

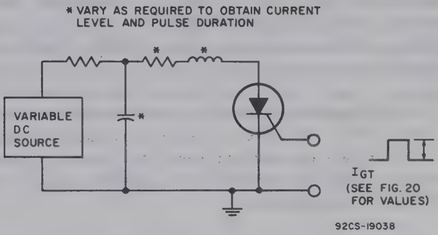

* VARY AS REQUIRED TO OBTAIN CURRENT LEVEL AND PULSE DURATION
*
*
*
VARIABLE DC SOURCE
I_{GT} (SEE FIG. 20 FOR VALUES)
92CS-19038

Fig. 19—Sub-cycle surge capability test circuit.

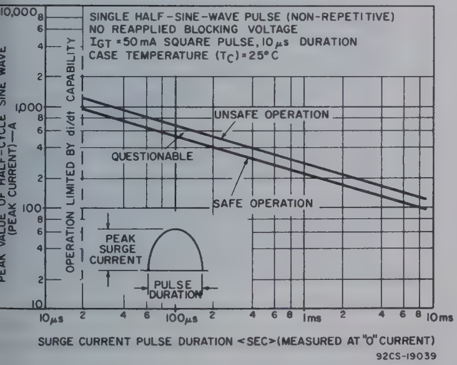


Fig. 20—Sub-cycle surge capability.

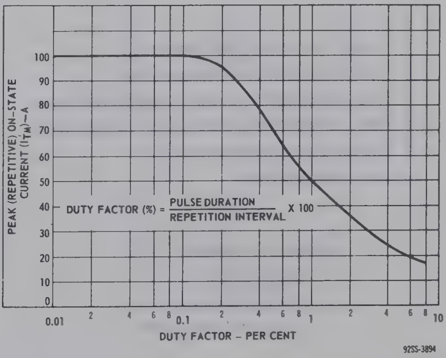


Fig. 21—Derating curve for peak pulse current (repetitive) vs. duty factor for the ignition circuit.

File No. 266

RCA
Solid State
Division

Thyristors

S2710 Series

JEDEC TO-66
With integral
heat radiator

H-1470A

1.7-Ampere Silicon Controlled Rectifiers

For Low-Cost Power-Control and Power-Switching Applications

Voltage / Package	200 V Type	400 V Type	600 V Type
TO-66 with Heat Radiator	S2710B (40504)	S2710B (40505)	S2710M (40506)

Numbers in parentheses are former RCA type numbers.

S2710B, S2710D, and S2710M are all-diffused, three-junction silicon controlled-rectifiers having integral heat radiators. They are variants of the 2N3228, 2N3525, and 2N4101, respectively.*

The S2710 series is designed to meet the needs of many power-control and power-switching applications in which heat sinks are required but where the design of special cooling systems to achieve the full current rating of the thyristor is not warranted.

The radiator design of these devices has tabs to allow printed-circuit board mounting and holes to allow chassis mounting if desired.

Thyristor with Heat Radiator	Thyristor without Heat Radiator
S2710B	2N3228
S2710D	2N3525
S2710M	2N4101

* Ratings and characteristics given for the 2N3228, 2N3225, and 2N4101 in RCA data bulletin File No. 114 are also applicable to the devices in the S2710 series.

Features:

- Forward and reverse gate ratings
- All-diffused center gate construction
- Low leakage currents, both forward and reverse
- Low forward voltage drop at high current levels
- High di/dt and dv/dt capability
- Low switching losses

TERMINAL CONNECTIONS

Pin 1: Gate
Pin 2: Cathode
Radiator, Case: Anode

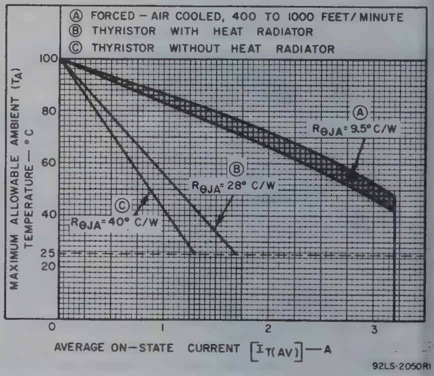
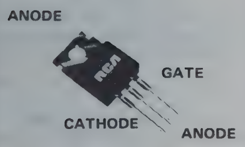


Fig. 1— Maximum allowable ambient temperature vs. on-state current

RCA
Solid State
Division

Thyristors

S2800 Series



JEDEC TO-220 AB

8-Ampere Silicon Controlled Rectifiers

For Power Switching, Power Control, and Ignition Applications

Features:

- **High dv/dt capability**
- **Low on-state voltage at high current levels**
- **Shorted-emitter gate-cathode construction . . . contains an internally diffused resistor between gate and cathode**
- **Low thermal resistance**
- **Center gate construction . . . provides rapid uniform gate-current spreading for faster turn-on with substantially reduced heating effects**

Package \ Voltage	100 V Type	200 V Type	400 V Type
TO-220AB	S2800A (40867)	S2800B (40868)	S2800D (40869)

Numbers in parentheses are former RCA type numbers.

2800A, S2800B, and S2800D are medium-power silicon ontrolled rectifiers designed for switching ac and dc urrents. These reverse-blocking thyristors switch from the ff-state to the on-state when both the anode and gate oltages are positive. Negative anode voltages make these evices revert to the blocking state regardless of gate-voltage olarity.

The unique plastic package design provides easy package mounting and low thermal resistance, allowing operation at high case temperatures and permitting reduced heat-sink size. These SCRs can be used in lighting and motor-speed control, capacitor-discharge ignition circuits, high-voltage generators, automotive applications, and power-switching systems.

AXIMUM RATINGS, *Absolute-Maximum Values:*		S2800A	S2800B	S2800D	
ON-REPETITIVE PEAK REVERSE VOLTAGE*					
Gate Open	V_{RSOM}	125	250	500	V
ON-REPETITIVE PEAK FORWARD VOLTAGE*					
Gate Open	V_{DSOM}	125	250	500	V
EPETITIVE PEAK REVERSE VOLTAGE*					
Gate Open	V_{RROM}	100	200	400	V
EPETITIVE PEAK OFF-STATE VOLTAGE*					
Gate Open	V_{DROM}	100	200	400	V
MS ON-STATE CURRENT					
For T_C of +80°C and Conduction Angle of 180°	$I_{T(RMS)}$	8	8	8	A
EAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}				
For one cycle of 400-Hz applied principal voltage. , $T_C = 80°C$		200	200	200	A
For one cycle of 60-Hz applied principal voltage , $T_C = 80°C$		100	100	100	A
For one cycle of 50-Hz applied principal voltage , $T_C = 80°C$		85	85	85	A
For more than one full cycle of applied principal voltage			See Fig. 7.		
ATE OF CHANGE OF ON-STATE CURRENT					
$V_D = V_{DROM}$, $I_{GT} = 80$ mA, $t_r = 0.5$ μs (See Fig. 3)	di/dt	100	100	100	A/μs
USING CURRENT (for SCR protection):					
$T_J = -65$ to 100°C, t = 1 to 8.3 ms	I^2t	40	40	40	A^2s
ATE POWER DISSIPATION▲:					
PEAK FORWARD (for 10 μs max.)	P_{GM}	16	16	16	W
PEAK REVERSE	P_{RGM}		See Fig. 13.		
AVERAGE (averaging time = 10 ms max.)	$P_{G(AV)}$	0.5	0.5	0.5	W
EMPERATURE RANGE♦:					
Storage			-65 to +150		°C
Operating (Case)			-65 to +100		°C
Soldering (10 sec. max.)			250		°C

These values do not apply if there is a positive gate signal. Gate must be open or negatively biased.

Any values of peak gate current or peak gate voltage which result in an equal or lower power are permissible.

For information on the reference point of temperature measurement, see Dimensional Outline.

ELECTRICAL CHARACTERISTICS, *At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified.*

CHARACTERISTIC	SYMBOL	LIMITS									UNITS
		S2800A			S2800B			S2800D			
		MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	
PEAK OFF-STATE CURRENT: (Gate Open, T_C = +100°C) FORWARD, $V_D = V_{DROM}$	I_{DOM}	–	0.1	2	–	0.1	2	–	0.1	2	mA
REVERSE (REPETITIVE), $V_R = V_{RROM}$	I_{ROM}	–	0.1	3	–	0.1	3	–	0.1	3	mA
INSTANTANEOUS ON-STATE VOLTAGE: For i_T = 30 A and T_C = +25°C	v_T	–	1.7	2.0	–	1.7	2.0	–	1.7	2.0	V
DC GATE TRIGGER CURRENT: V_D = 12 V (DC) R_L = 30 Ω T_C = +25°C	I_{GT}	–	8	15	–	8	15	–	8	15	mA
For other case temperatures		See Fig. 9.									
DC GATE TRIGGER VOLTAGE: V_D = 12 V (DC) R_L = 30 Ω T_C = +25°C	V_{GT}	–	0.9	1.5	–	0.9	1.5	–	0.9	1.5	V
For other case temperatures		See Fig. 10.									
INSTANTANEOUS HOLDING CURRENT: Gate Open and T_C = +25°C	i_{HO}	–	10	20	–	10	20	–	10	20	mA
For other case temperatures		See Fig. 11.									
CRITICAL RATE-OF-RISE OF OFF-STATE VOLTAGE: $V_D = V_{DROM}$ Exponential rise, T_C = +100°C (See Fig. 2.)	dv/dt	75	300	–	50	300	–	30	200	–	V/μs
For other case temperatures		See Fig. 14.									
GATE CONTROLLED TURN-ON TIME: $V_D = V_{DROM}$, i_T = 4.5 A, i_T = 2 A I_{GT} = 80 mA, 0.1 μs rise time T_C = +25°C (See Fig. 5.)	t_{gt}	–	1.6	2.5	–	1.6	2.5	–	1.6	2.5	μs
CIRCUIT COMMUTATED TURN-OFF TIME: $V_D = V_{DROM}$, i_T = 2 A Pulse Duration = 50 μs dv/dt = 200 V/μs, di/dt = –10 A/μs I_{GT} = 200 mA at turn on, T_C = +75°C (See Fig. 4.)	t_q	–	10	35	–	10	35	–	10	35	μs
THERMAL RESISTANCE: Junction-to-Case	$R_{\theta J\text{-}C}$	–	–	2.2	–	–	2.2	–	–	2.2	°C/W
Junction-to-Ambient	$R_{\theta J\text{-}A}$	–	–	60	–	–	60	–	–	60	

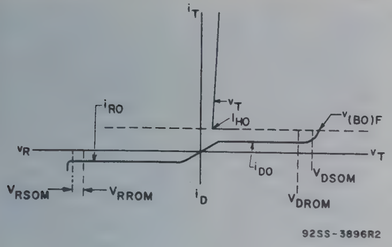

iT
iRO
vT
IHO
v(BO)F
vR
vT
iDO
VDSOM
VRSOM
VRROM
iD
VDROM
92SS-3896R2

Fig. 1—Principal voltage-current characteristic.

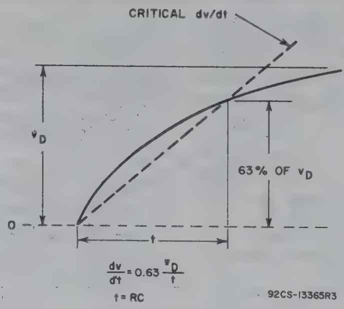
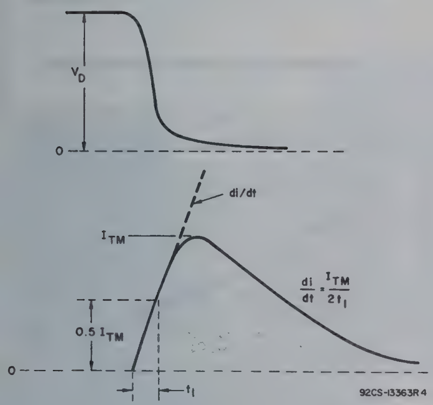

CRITICAL dv/dt
vD
63% OF vD
0
t
$\frac{dv}{dt} = 0.63 \frac{v_D}{t}$
t = RC
92CS-13365R3

Fig. 2—Rate of rise of off-state voltage with time (defining critical dv/dt).


VD
0
di/dt
ITM
$\frac{di}{dt} = \frac{I_{TM}}{2t_1}$
0.5 ITM
0
t1
92CS-13363R4

ig. 3—Rate of change of on-state current with time (defining di/dt).

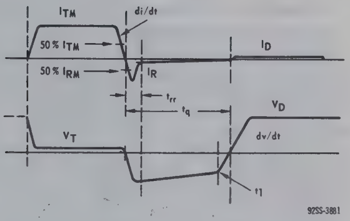
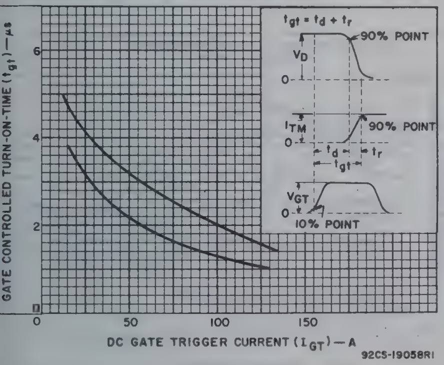

ITM
di/dt
50% ITM
ID
50% IRM
IR
trr
tq
VD
VT
dv/dt
t1
92SS-3881

Fig. 4—Relationship between instantaneous on-state current and voltage, showing reference points for definition of circuit-commutated turn-off time (t_q).



g. 5—Typical gate-controlled turn-on time vs. gate trigger current.

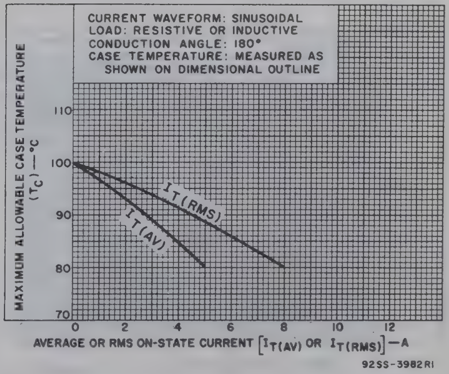


Fig. 6—Maximum allowable case temperature vs. on-state current.

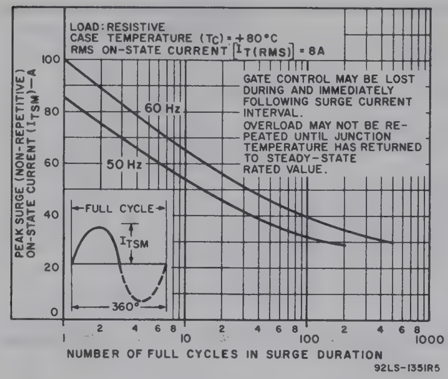


Fig. 7—Allowable peak surge on-state current vs. surge duration.

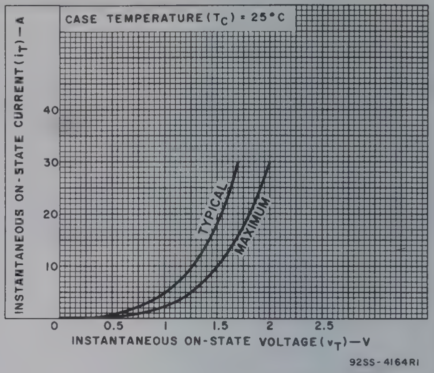


Fig. 8—Instantaneous on-state current vs. on-state voltage.

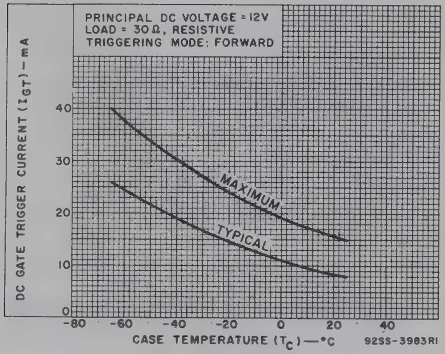


Fig. 9—DC gate-trigger current (forward) vs. case temperature.

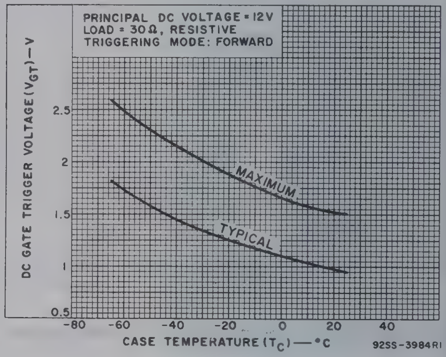


Fig. 10—DC gate-trigger voltage (forward) vs. case temperature.

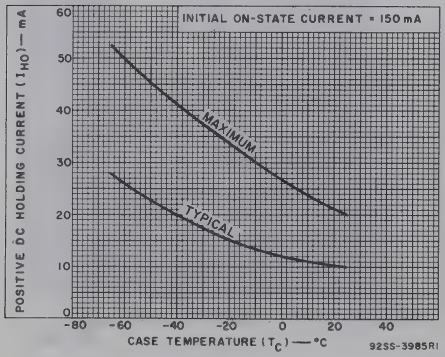


Fig. 11—Holding current (positive) vs. case temperature.

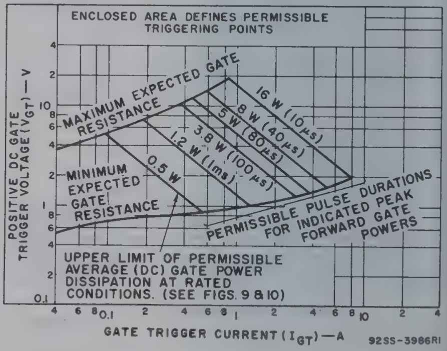


Fig. 12—Typical forward-biased gate characteristics.

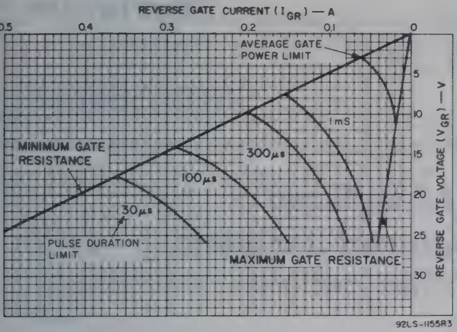


Fig. 13—Reverse gate voltage vs. reverse gate current.

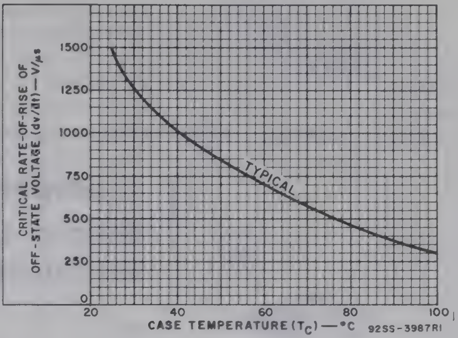


Fig. 14—Critical rate of rise of off-state voltage vs. case temperature.

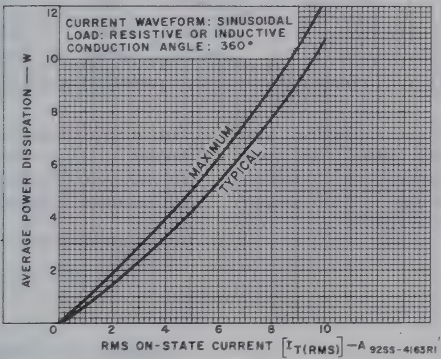


Fig. 15—Power dissipation vs. on-state current.

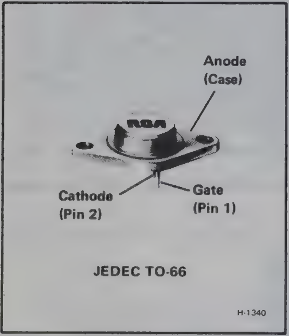
TERMINAL CONNECTIONS

No. 1 — Cathode
Mounting Flange, No. 2 — Anode
No. 3 — Gate

RCA
Solid State Division

Thyristors

S3700 Series



JEDEC TO-66

5-Ampere All-Diffused Silicon Controlled Rectifiers for Inverter Applications

Voltage / Package	200 V Type	400 V Type	600 V Type
TO-66	S3700B (40553)	S3700D (40554)	S3700M (40555)

Numbers in parentheses are former RCA type numbers.

S3700B, S3700D, and S3700M* are all-diffused three-junction silicon controlled rectifiers intended for use in inverter applications such as ultrasonics and fluorescent lighting. They feature fast turn-off, high dv/dt, and high di/dt characteristics, and may be used at frequencies up to 25 kHz.

Each of these devices has an rms on-state current rating of 5 amperes at a case temperature of +60°C. The S3700B, S3700D, and S3700M have forward and reverse off-state voltage ratings of 200, 400, and 600 volts, respectively.

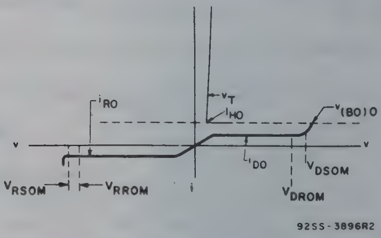
---

*Formerly Developmental Types TA2653, TA2654, and TA2655, respectively.

Features:

- **RMS On-State Current –**
  5 Amperes at T_C = + 60° C
- **Fast Turn-Off Time –**
  6 μs maximum
- **High dv/dt Capability –**
  100 V/μs minimum
- **High di/dt Capability –**
  200 A/μs
- **Shorted-Emitter and Center-Gate Design –**
  Removes restrictions on forward and reverse gate voltage and peak gate current

PRINCIPAL VOLTAGE-CURRENT CHARACTERISTIC



Principal voltage is the voltage between the main terminals. Principal voltage is called positive, or forward, when the anode potential is higher than the cathode potential, and called negative when the anode potential is lower than the cathode potential.

Principal current is the current flowing between anode and cathode.

Absolute-Maximum Ratings, for Operation with Sinusoidal AC Supply Voltage At Low to Ultrasonic Frequencies, and with Resistive or Inductive Load

RATINGS	MAXIMUM VALUES			UNITS
	S3700B	S3700D	S3700M	
Non-Repetitive Peak Reverse Voltage, V_{RSOM}				
Gate Open	330	660	700	V
Repetitive Peak Reverse Voltage, V_{RROM}				
Gate Open	200	400	600	V
Repetitive Peak Off-State Voltage, V_{DROM}				
Gate Open	200	400	600	V
On-State Current:				
For case temperature of +60° C and 60 Hz				
Average DC value at a conduction angle of 180°, $I_{T(AV)}$	3.2	3.2	3.2	A
RMS value, $I_{T(RMS)}$	5	5	5	A
For other conditions	See *Fig.9*			
Peak Surge (Non-Repetitive) On-State Current, I_{TSM}				
For one cycle of applied voltage, T_C = 60°C				
60 Hz (sinusoidal)	80	80	80	A
50 Hz (sinusoidal)	65	65	65	A
For more than one cycle of applied voltage	See *Fig.11*			
Fusing Current (for SCR protection):				
T_J = −40 to 100°C, t = 1 to 8.3 ms, I^2t . .	25	25	25	A^2s
Critical Rate of Rise of On-State Current, Critical di/dt				
$V_{DX} = V_{(BO)O}$ rated value, I_{GT} = 50 mA, 0.1 μs rise time	200	200	200	A/μs
Gate Power Dissipation*				
Peak, Forward or Reverse, for 10 μs duration, P_{GM}	13	13	13	W
Average, $P_{G(AV)}$	0.5	0.5	0.5	W
Temperature:■				
Storage, T_{stg}	-40 to +150	-40 to +150	-40 to +150	°C
Operating (Case), T_C	-40 to +100	-40 to +100	-40 to +100	°C

*Any values of peak gate current or peak gate voltage to give the maximum gate power are permissible.

■For information on the reference point of temperature measurement, see *Dimensional Outline.*

Characteristics at Maximum Ratings (unless otherwise specified), and at Indicated Case Temperature (T_C)

CHARACTERISTICS	LIMITS									UNITS
	S3700B			S3700D			S3700M			
	Min.	*Typ.*	*Max.*	*Min.*	*Typ.*	*Max.*	*Min.*	*Typ.*	*Max.*	
Peak Repetitive Blocking Voltage, V_{DROM} Gate Open At T_C = +100° C	200	–	–	400	–	–	600	–	–	V
Peak Off-State Current: Gate Open At T_C = +100° C										
Forward, I_{DOM} $V_D = V_{DROM}$	–	0.5	3	–	0.5	3	–	0.5	3	mA
Reverse, I_{RROM} $V_{RO} = V_{RROM}$	–	0.3	1.5	–	0.3	1.5	–	0.3	1.5	mA
Instantaneous On-State Voltage, v_T For an on-state current of 30 A and T_C = +25° C (See *Fig.13*)	–	2.2	3	–	2.2	3	–	2.2	3	V
DC Gate Trigger Current, I_{GT} At T_C = +25° C (See *Fig.5*)	–	15	40	–	15	40	–	15	40	mA(dc)
DC Gate Trigger Voltage, V_{GT} At T_C = +25° C (See *Fig.5*)	–	1.8	3.5	–	1.8	3.5	–	1.8	3.5	V(dc)
Holding Current, I_H At T_C = +25° C	–	20	50	–	20	50	–	20	50	mA
Critical Rate of Rise of Off-State Voltage, Critical dv/dt $V_D = V_{DROM}$, linear rise, and T_C = +80°C (See waveshapes of *Fig.2*)	100	250	–	100	250	–	100	250	–	V/µs
Gate-Controlled Turn-On Time, t_{gt} (Delay Time + Rise Time) $V_{DX} = V_{DROM}$, I_{TM} = 2 A, I_{GT} = 300 mA, 0.1 µs rise time, and T_C = +25°C (See waveshapes of *Fig.3*)	–	0.7	–	–	0.7	–	–	0.7	–	µs
Circuit-Commutated Turn-Off Time, t_q (Reverse Recovery Time + Gate Recovery Time) $V_{DX} = V_{(BO)O}$ rated value, I_{TM} = 2 A, 50 µs min. pulse width, V_{RX} = 80 V min., rise time = 0.1 µs, dv/dt = 100 V/µs, di_R/dt = 10 A/µs, I_{GT} = 100 mA at turn-on, V_{GT} = 0 V at turn-off, and T_C = +80° C (See waveshapes of *Fig.4*)	–	4	6	–	4	6	–	4	6	µs
Thermal Resistance:										
Junction-to-case, $R_{\theta JC}$	–	–	8	–	–	8	–	–	8	°C/W
Junction-to-ambient, $R_{\theta JA}$	–	–	40	–	–	40	–	–	40	°C/W

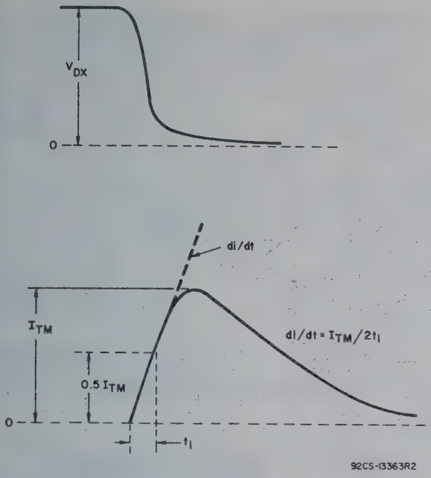

VDX
0
di/dt
ITM
di/dt = ITM/2t1
0.5 ITM
0
t1
92CS-13363R2

Fig. 1—Waveshape of di/dt rating test.

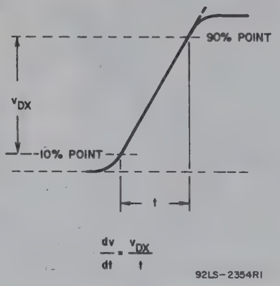

90% POINT
VDX
10% POINT
t
dv/dt = VDX/t
92LS-2354R1

Fig. 2—Waveshape of critical dv/dt rating test (linear rise).

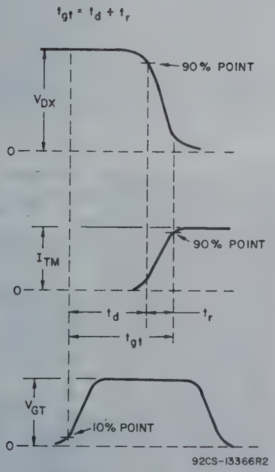

tgt = td + tr
90% POINT
VDX
0
ITM
90% POINT
0
td
tr
tgt
VGT
10% POINT
0
92CS-13366R2

Fig. 3—Waveshape of t_{gt} rating test.

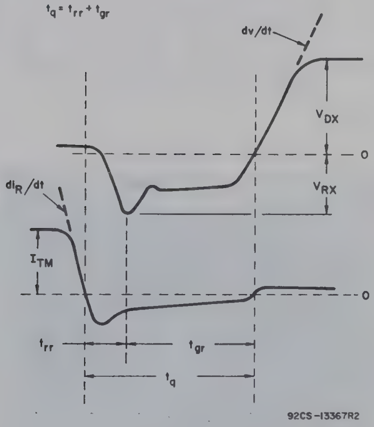

tq = trr + tgr
dv/dt
VDX
0
VRX
diR/dt
ITM
0
trr
tgr
tq
92CS-13367R2

Fig. 4—Waveshape of t_q rating test.

TERMINAL CONNECTIONS

Pin 1 — Gate
Pin 2 — Cathode
Case, Mounting Flange — Anode

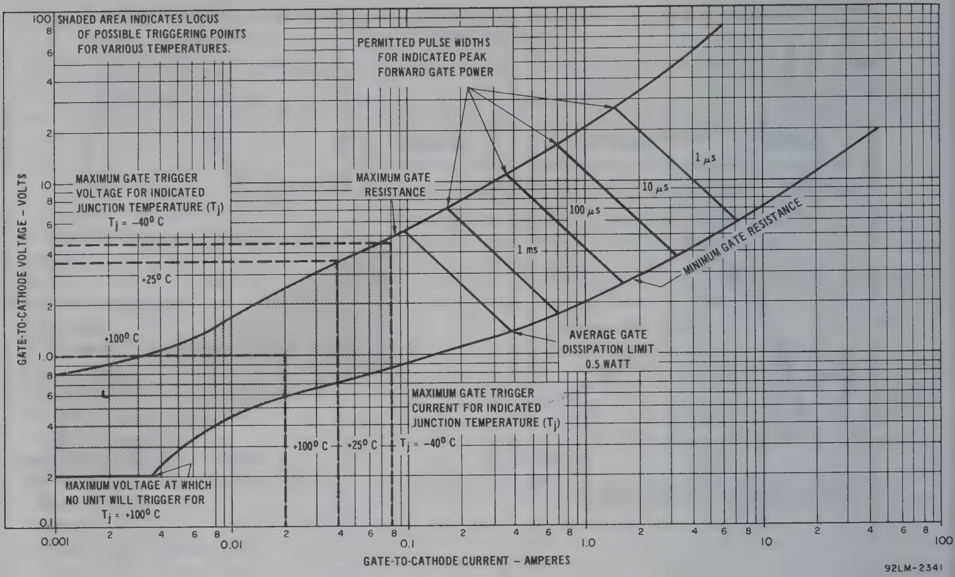


Fig. 5—Forward gate characteristics.

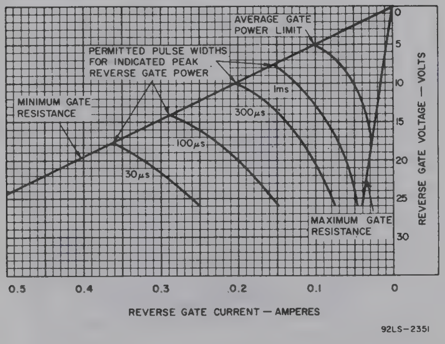


Fig. 6—Reverse gate characteristics.

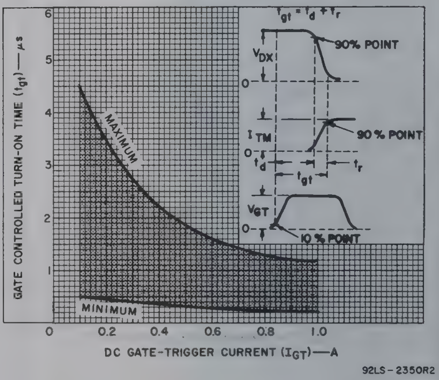


Fig. 7— Turn-on-time characteristics.

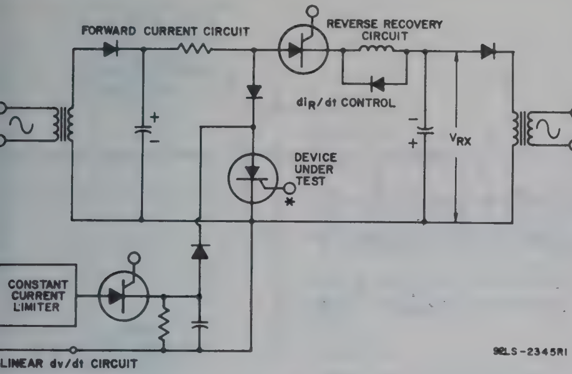

FORWARD CURRENT CIRCUIT
REVERSE RECOVERY CIRCUIT
di_R/dt CONTROL
V_RX
DEVICE UNDER TEST
*
CONSTANT CURRENT LIMITER
LINEAR dv/dt CIRCUIT
92LS-2345R1

Fig. 8—Conventional turn-off-time test circuit.

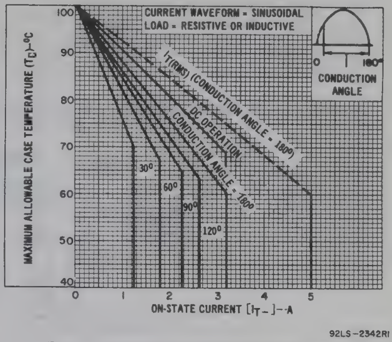


Fig. 9—Rating chart (case temperature).

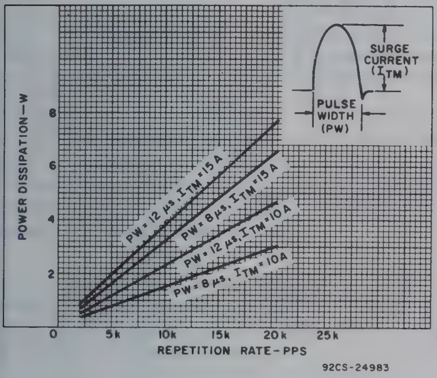


Fig. 10 — Dissipation vs. repetition rate.

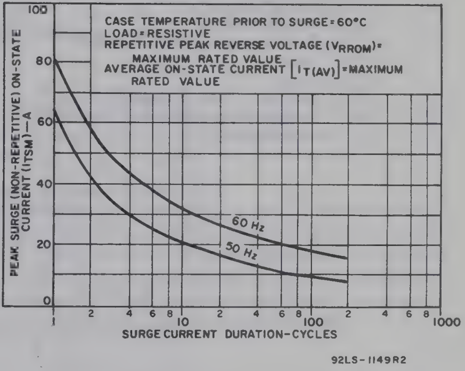


Fig. 11—Surge current rating.

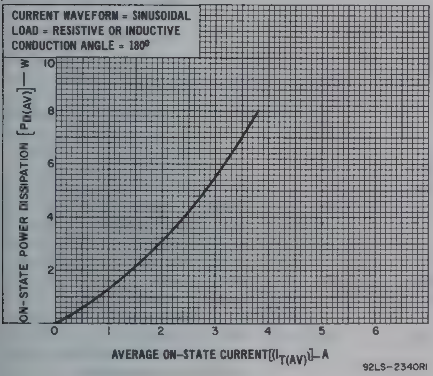


Fig. 12—Power dissipation versus average on-state current.

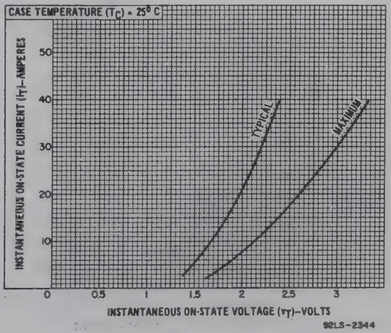
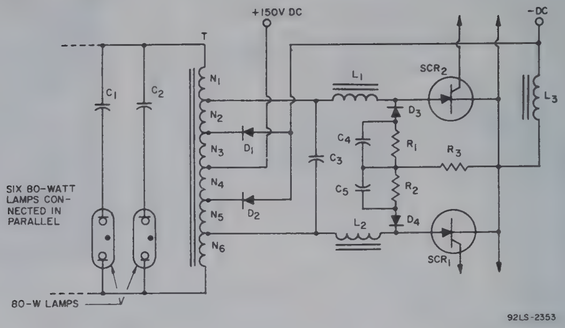


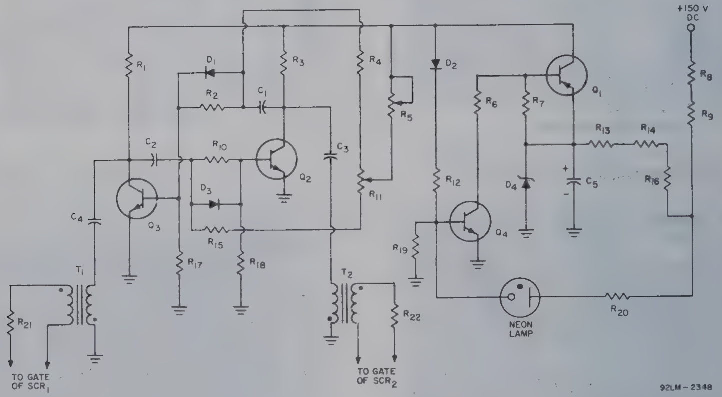
Fig. 13—On-state characteristics.


+150V DC
-DC
T
C1
C2
N1
N2
N3
N4
N5
N6
D1
D2
L1
L2
L3
SCR2
SCR1
D3
D4
C3
C4
C5
R1
R2
R3
SIX 80-WATT LAMPS CONNECTED IN PARALLEL
80-W LAMPS
92LS-2353

C_1, C_2: 0.01 μF, 1200 V (Ballast Capacitors)
C_3: 0.01 μF, 600 V
C_4, C_5: 0.02 μF, 600 V
D_1, D_2: Fast-Recovery Diodes, 6 A, 600 V
D_3, D_4: 1N574
L_1, L_2: 32 μH
L_3: 131 Turns of No.15 Magnet Wire on Arnold Engineering Core No.A4-04117, or equivalent

R_1, R_2: 1.2 kΩ, 5 W
R_3: 200 Ω, 10 W
T: Core, 8 pieces of Indiana General No. CF-602 Material 05, or equivalent.
Cross Section, 8 cm^2
N_1, N_6 – 30 Turns of No.18 Magnet Wire
N_2, N_5 – 13 Turns of No.18 Magnet Wire, 2 Strands
N_3, N_4 – 52 Turns of No.18 Magnet Wire, 2 Strands

Fig. 14—Typical inverter circuit for 500-watt. 8-kHz fluorescent-light control.


+150 V DC
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22
D1
D2
D3
D4
C1
C2
C3
C4
C5
Q1
Q2
Q3
Q4
T1
T2
NEON LAMP
TO GATE OF SCR1
TO GATE OF SCR2
92LM-2348

Q_1: RCA-40438
Q_2, Q_3, Q_4: RCA-2N3053
C_1, C_2: 0.003 μF, 100 V
C_3, C_4: 0.02 μF, 100 V
C_5: 25 μF, 25 V, electrolytic
D_1, D_2, D_3: Transitron type T1G, or equivalent
D_4: Motorola type 1M20Z10, or equivalent
Neon Lamp: GE type NE-83, or equivalent
R_1, R_3: 1 kΩ, 1/4 watt
R_2, R_{10}: 180 kΩ, 1/4 watt

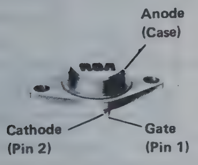
R_4, R_{12}, R_{15}, R_{17}, R_{18}: 22 kΩ, 1/4 watt
R_5, R_{11}: 10 kΩ potentiometer
R_6: 10 kΩ, 1/4 watt
R_7: 1.5 kΩ, 1/4 watt
R_8, R_9, R_{13}, R_{14}, R_{16}: 680 Ω, 2 watts
R_{19}: 5.6 kΩ, 1/4 watt
R_{20}: 33 kΩ, 1/4 watt
R_{21}, R_{22}: 10 Ω, 1/4 watt
T_1, T_2: Sprague Pulse Transformer type 42Z109, or equivalent

Fig. 15—Typical trigger pulse generator for 500-watt, 8-kHz fluorescent-light control inverter circuit.

RCA
Solid State Division

Thyristors

S3701M



JEDEC TO-66

H-1340

5-Ampere Silicon Controlled Rectifier

For Applications in Pulse Power Supplies
To Drive GaAs Laser Diodes

Features:

- High peak-current capability
- Good current-spreading attributes
- Symmetrical gate-cathode construction for uniform current density, rapid electrical conduction, and efficient heat dissipation
- Controlled minimum holding current
- Hermetic construction
- Low thermal resistance

ype S3701M● is a silicon controlled rectifier intended for se in circuits which generate pulses to drive injection laser iodes. A simplified circuit of a laser pulser is shown in Fig. . Detailed information on circuits of this type is given in CA Application Note AN-4469, "Solid-State Pulse Power upplies for RCA GaAs Injection Lasers."

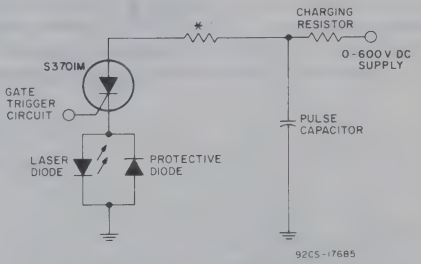
he conventional SCR turn-on time, turn-off time, and n-state voltage do not correlate with circuit performance in laser pulser operating with extremely short, high-current pulses. Therefore, a functional test in a simulated pulser circuit is used to control the S3701M for laser pulser application.

The S3701M SCR is designed for the good current-spreading and delay-time characteristics necessary to provide high-peak-current pulses to drive the laser diode. An additional significant characteristic of this device is its well controlled holding current, which assures operation only at currents sufficiently high to meet the circuit requirements.

● Formerly RCA type 40768.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
Case temperature (T_C) = 25°C, unless otherwise specified

REPETITIVE PEAK OFF-STATE VOLTAGE:			
Gate open	V_{DROM}	600	V
RMS ON-STATE CURRENT (Conduction angle = 180°)	$I_{T(RMS)}$	5	A
REPETITIVE PEAK ON-STATE CURRENT (0.2 μs Pulse Width):	I_{PM}		
Free-air cooling, f = 500 Hz		75	A
Free-air cooling, f = 5000 Hz		40	A
Infinite heat sink, f = 10,000 Hz		40	A
Infinite heat sink, f = 1,000 Hz		75	A
GATE POWER DISSIPATION:			
PEAK (For 10 μs pulse)	P_{GM}	25	W
TEMPERATURE RANGE:			
Storage	T_{stg}	-40 to 125	°C
Operating (Case)	T_C	-40 to 100	°C
TERMINAL TEMPERATURE (During soldering):	T_T		
For 10 s max. (terminals and case)		225	°C



* NON-INDUCTIVE RESISTOR
ADJUST RESISTANCE VALUE TO OBTAIN 0.20 μs PULSE WIDTH AT 50 % CURRENT POINTS

Fig. 1—Simplified laser pulser circuit. (See AN-4469 for specific circuits.)

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	SYMBOL	LIMITS		UNITS
		Min.	Max.	
Peak Off-State Current: Gate open, $v_D = V_{DROM}$, $T_C = 25^oC$ $T_C = 75^oC$	I_{DROM}	– –	0.65 1.2	mA
DC Gate-Trigger Current: $T_C = 25^oC$	I_{GT}	–	35	mA
DC Gate-Trigger Voltage: $T_C = 25^oC$	V_{GT}	–	4	V
DC Holding Current: Gate open, $T_C = 25^oC$ $T_C = 75^oC$	I_{HO}	15 10	– –	mA
Critical Rate-of-Rise of Off-State Voltage: For $v_D = V_{DROM}$, exponential voltage rise, gate open, $T_C = 75^oC$	dv/dt	200	–	V/μs
Source Voltage for Functional Test (See Fig. 2): $I_p = 75A$, $C = 0.022\mu F$, $R_s = 2\Omega$, f = 60Hz, pulse duration = 0.2μs, $T_C = 25^oC$	V_s	–	550	V
Thermal Resistance: Junction-to-Case Junction-to-Ambient	$R_{\theta JC}$ $R_{\theta JA}$	– –	7 40	$^oC/W$

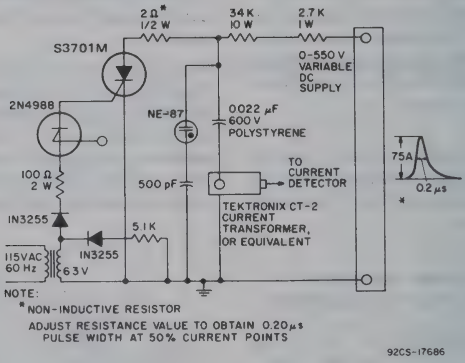

2 Ω*
1/2 W
34 K
10 W
2.7 K
1 W
S3701M
0-550 V
VARIABLE
DC
SUPPLY
2N4988
NE-87
0.022 μF
600 V
POLYSTYRENE
75A
0.2 μs
*
100 Ω
2 W
500 pF
TO
CURRENT
DETECTOR
TEKTRONIX CT-2
CURRENT
TRANSFORMER,
OR EQUIVALENT
IN3255
5.1 K
115VAC
60 Hz
IN3255
6.3 V
NOTE:
* NON-INDUCTIVE RESISTOR
ADJUST RESISTANCE VALUE TO OBTAIN 0.20 μs
PULSE WIDTH AT 50% CURRENT POINTS
92CS-17686

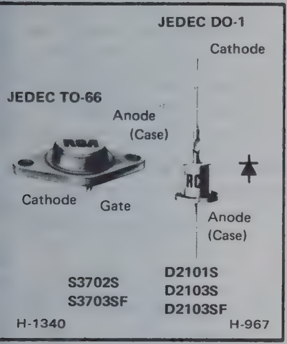
Fig. 2–Functional test circuit.

TERMINAL CONNECTIONS

Pin 1 – Gate
Pin 2 – Cathode
Case, Mounting Flange – Anode

RCA
Solid State
Division

Thyristors/Rectifiers
S3702S D2101S
S3703SF D2103S
D2103SF


JEDEC DO-1
Cathode
JEDEC TO-66
Anode
(Case)
Cathode
Gate
Anode
(Case)
S3702S
S3703SF
D2101S
D2103S
D2103SF
H-1340
H-967

SCR's and Rectifiers for Horizontal-Deflection Circuits

For 110° Large-Screen Color TV

Features:

- Operation from supply voltages between 150 and 270 V (nominal)
- Ability to handle high beam current; average 1.6 mA dc
- Ability to supply as much as 8 mJ of stored energy to the deflection yoke, which is sufficient for 29-mm-neck and 36.5-mm-neck picture tubes operated at 31 kV (nominal value)
- Highly reliable circuit which can also be used as a low-voltage power supply

Package \ Voltage	700 V Types	750 V Types
TO-66	S3702S (40889)	S3703SF (40888)
DO-1	D2101S D2103S (40892) (40891)	D2103SF (40890)

Numbers in parentheses are former RCA type numbers.

These RCA types are designed for use in a horizontal output circuit such as that shown in Fig. 1.

The S3703SF silicon controlled rectifier and the D2103SF silicon rectifier are designed to act as a bipolar switch that controls horizontal yoke current during the beam trace interval. The S3702S silicon controlled rectifier and the D2103S silicon rectifier act as the commutating switch to initiate trace-retrace switching and control yoke current during retrace.

The D2101S silicon rectifier may be used as a clamp to protect the circuit components from excessively high transient voltages which may be generated as a result of arcing in the picture tube or in a high-voltage rectifier tube.

To facilitate direct connection across each silicon controlled rectifier, S3702S and S3703SF, the anode connections of silicon rectifiers D2103S and D2103SF are reversed as compared to that of a normal power-supply rectifier diode.

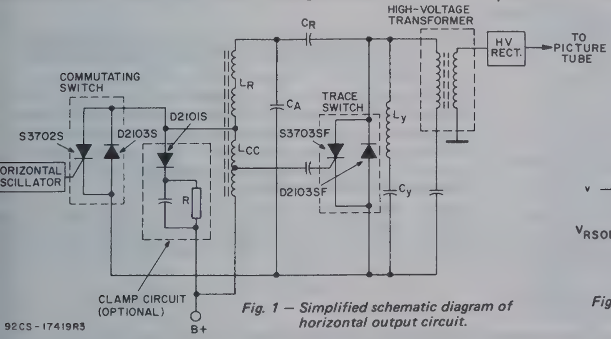

HIGH-VOLTAGE
TRANSFORMER
CR
HV
RECT.
TO
PICTURE
TUBE
COMMUTATING
SWITCH
LR
CA
TRACE
SWITCH
Ly
D2101S
S3702S
D2103S
S3703SF
ORIZONTAL
SCILLATOR
LCC
D2103SF
Cy
R
CLAMP CIRCUIT
(OPTIONAL)
B+
92CS-17419R3

Fig. 1 — Simplified schematic diagram of horizontal output circuit.

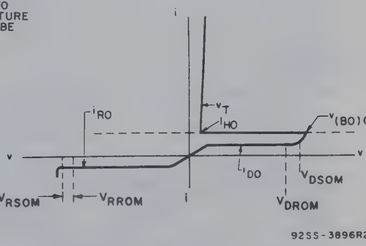


Fig. 2 — Principal voltage-current characteristic for S3702S and S3703SF.

SILICON CONTROLLED RECTIFIERS

MAXIMUM RATINGS, *Absolute-Maximum Values:*		S3703SF TRACE SCR	S3702S COMMUTATING SCR	
NON-REPETITIVE PEAK OFF-STATE VOLTAGE:●				
Gate Open	V_{DSOM}	800*	750*	V
REPETITIVE PEAK REVERSE VOLTAGE:●				
Gate Open	V_{RROM}	25	25	V
REPETITIVE PEAK OFF-STATE VOLTAGE:●				
Gate Open	V_{DROM}	750	700	V
ON-STATE CURRENT:				
T_C = 60°C, 50 Hz sine wave, conduction angle = 180°:				
RMS	$I_{T(RMS)}$	5	5	A
Average DC	$I_{T(AV)}$	3.2	3.2	A
PEAK SURGE (NON–REPETITIVE) ON-STATE CURRENT:	I_{TSM}			
For one full cycle of applied principal voltage 50 Hz (sinusoidal), T_C = 60°C		65	65	A
For one-half sine wave, 3 ms pulse width		130	130	A
RATE OF CHANGE OF ON-STATE CURRENT:				
$V_D = V_{DROM}$, I_{GT} = 50 mA, t_r = 0.1 μs	di/dt	200	200	A/μs
FUSING CURRENT (for SCR protection):				
T_J = −40 to 80°C, t = 1 to 10 ms	I^2t	20	20	A^2s
GATE POWER DISSIPATION:■	P_{GM}			
Peak (forward or reverse) for 10 μs duration, max. negative gate bias = −35 V (S3703SF)		25	—	W
= −10 V (S3702S)		—	25	W
TEMPERATURE RANGE:▲				
Storage	T_{stg}	−40 to 150	−40 to 150	°C
Operating (Case)	T_C	−40 to 80	−40 to 80	°C
PIN TEMPERATURE (During soldering):				
At distances ≥ 1/32 in. (0.8 mm) from seating plane for 10 s max.	T_P	225	225	°C

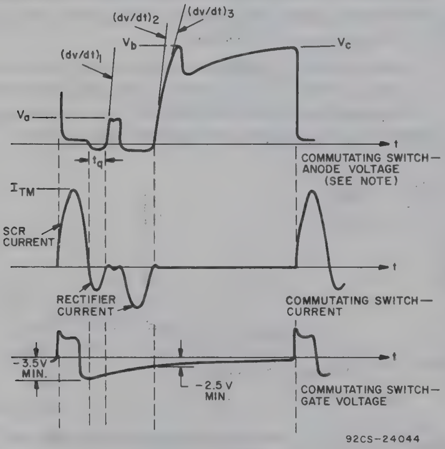
---

*Protection against transients induced by arcing or other causes must be provided.

●These values do not apply if there is a positive gate signal. Gate must be open or negatively biased.

■Any product of gate current and gate voltage which results in a gate power less than the maximum is permitted, provided that the maximum reverse gate bias (as specified) is not exceeded.

▲For temperature measurement reference point, see Dimensional Outline.



NOTE: "Commutating Switch-Anode Voltage" oscilloscope display has been modified graphically to enhance the measurement points of dv/dt.

I_{TM} = 15 A, V_a = 180 V max., V_b = 500 V max., $V_c = V_{DROM}$. Gate voltage = 12 V positive from 15 V supply. Gate current should rise to 100 mA within 0.2 μs. Minimum duration of gate current pulse = 3 μs. Minimum amplitude of gate current pulse = 200 mA. Negative gate bias at turn-off = −3.5 V minimum, negative gate bias at 2nd reapplied voltage $(dv/dt)_2$ = −2.5 V minimum.

$(dv/dt)_1$ = 400 V/μs (measured tangent to waveform from 0 to 0.8 of V_a)
$(dv/dt)_2$ = 1000 V/μs (measured tangent to waveform from 0 to 0.3 of V
$(dv/dt)_3$ = 700 V/μs (measured tangent to waveform from 0 to 0.8 of V_b

Fig. 3 – Oscilloscope display of commutating switching (S3702S) showing circuit-commutated turn-off time (tq).

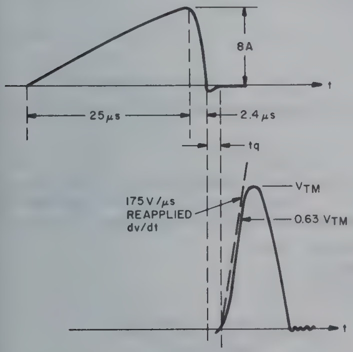
SILICON CONTROLLED RECTIFIERS

ELECTRICAL CHARACTERISTICS

At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS				UNITS
		S3703SF TRACE SCR		S3702S COMMUTATING SCR		
		TYP.	MAX.	TYP.	MAX.	
Peak Forward Off-State Current: Gate open, $V_D = V_{DROM}$ $T_C = 85°C$ . .	I_{DOM}	0.5	1.5	0.5	1.5	mA
Instantaneous On-State Voltage: i_T = 30 A (peak), $T_C = 25°C$	v_T	2.2	3	2.2	3	V
Critical Rate of Rise of Off-State Voltage: $V_D = V_{DROM}$, exponential voltage rise, Gate open, $T_C = 70°C$ (See Fig.3)	dv/dt	–	–	700 (min.) $(dv/dt)_3$		V/μs
DC Gate Trigger Current: V_D = 12 V (dc), R_L = 30 Ω, $T_C = 25°C$	I_{GT}	15	32	15	45	mA
DC Gate Trigger Voltage: V_D = 12 V (dc), R_L = 30 Ω, $T_C = 25°C$	V_{GT}	1.8	4	1.8	4	V
Circuit Commutated Turn-Off Time:◆ $T_C = 70°C$, minimum negative gate bias during turn-off time = –20 V (S3703SF) and –2.5 V (S3702S), rate of reapplied voltage (dv/dt) = 175 V/μs (See Fig. 4) . . . . = 400 V/μs (See Fig. 3	t_q	– –	2.4 –	– –	– 4.2	μs μs
Thermal Resistance, Junction-to-Case . . .	$R_{\theta JC}$	–	4	–	4	°C/W

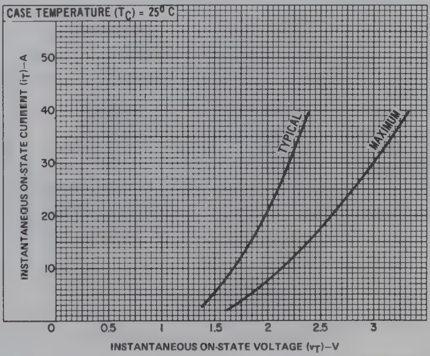
◆This parameter, the sum of reverse recovery time and gate recovery time, is measured from the zero crossing of current to the start of the reapplied voltage. Knowledge of the current, the reapplied voltage, and the case temperature is necessary when measuring t_q. In the worst conditions (high line, zero-beam, off-frequency, minimum auxiliary load, etc.), turn-off time must not fall below the given values. Turn-off time increases with temperature; therefore, case temperature must not exceed 70°C. See Figs. 3 and 4.



TM = 8 A, $V_{TM} = V_{DROM}$, reapplied dv/dt = 175 V/μs (measured
rom 0 to 0.63 of V_{TM}), negative gate voltage source = –24 V, source
npedance = 15 Ω.

92CS-24045

4 – Oscilloscope display of trace switching (S3703SF) showing circuit-commutating turn-off time (tq).



92LS-2344R1

Fig. 5 – Instantaneous on-state current vs. on-state voltage for S3702S and S3703SF.

SILICON RECTIFIERS

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		D2103SF TRACE	D2103S COMMUTATING	D2101S CLAMP	
REVERSE VOLTAGE:**					
Repetitive Peak	V_{RRM}	750	700	700	V
Non-Repetitive Peak●●	V_{RSM}	800	800	800	V
FORWARD CURRENT (operating in 15 kHz deflection circuit):					
RMS	$I_{F(RMS)}$	3■■	3■■	1**	A
Peak Surge (Non-Repetitive)●●	I_{FSM}	70◆◆	70◆◆	30◆◆	A
Peak (Repetitive)	I_{FRM}	7	12	0.5	A
TEMPERATURE RANGE					
Storage	T_{stg}	−30 to 150			°C
Operating (Case)	T_C	−30 to 80			°C
LEAD TEMPERATURE (During Soldering):▲▲					
For 10 s maximum	T_L	225			°C

** For ambient temperatures up to 45°C.

●● For a maximum of 3 pulses, each less than 10 μs duration, during any 64-μs period.

■■ Maximum current rating applies only if the rectifier is properly mounted to maintain junction temperature below 150°C. See Fig.15 and Fig.16

▲▲ At distances no closer to rectifier body than points A and B on outline drawing.

◆◆ See Fig. 9 for I_{FSM} value for 60 Hz.

SILICON RECTIFIERS

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS: D2103SF TRACE D2103S COMMUT. MAXIMUM	LIMITS: D2101S CLAMP MAXIMUM	UNITS
Reverse Current: *Static* For V_{RRM} = max. rated value, $I_F = 0$, $T_C = 25°C$ For $V_R = 500$ V, $T_C = 100°C$	I_{RM}	10 250	10 250	μA
Instantaneous Forward Voltage Drop: At $i_F = 4$ A, $T_A = 25°C$	v_F	1.4	1.5	V
Reverse Recovery Time: For circuit shown in Fig. 8: At $I_{FM} = 3.14$ A, $-di_F/dt = -10$ A/μs, pulse duration = 0.94 μs, $T_C = 25°C$	t_{rr}	0.5	0.7	μs
In Tektronix type "S" plug-in unit (or equivalent): At $I_F = 20$ mA, $I_R = 1$ mA $T_C = 25°C$		1	1.5	
Peak Forward Voltage Drop (at turn-on): In Tektronic type "S" plug-in unit (or equivalent): At $I_F = 20$ mA, $T_C = 25°C$	$V_{F(pk)}$	5	6	V
Thermal Resistance (Junction-to-Case)◆	$R_{\theta JC}$	10	10	°C/W

◆ Measured at point as indicated on Dimensional Outline.

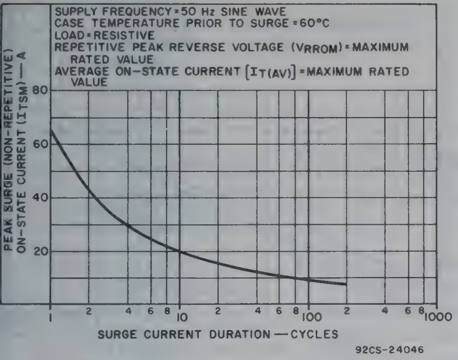


Fig. 6 – Peak surge on-state current vs. surge current duration for S3702S and S3703SF.

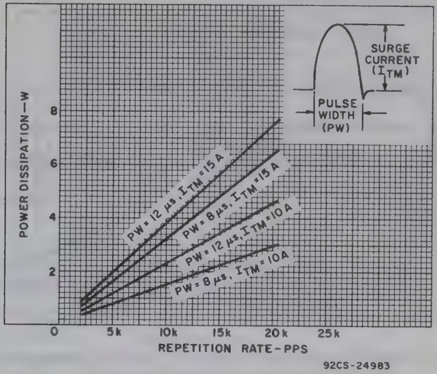
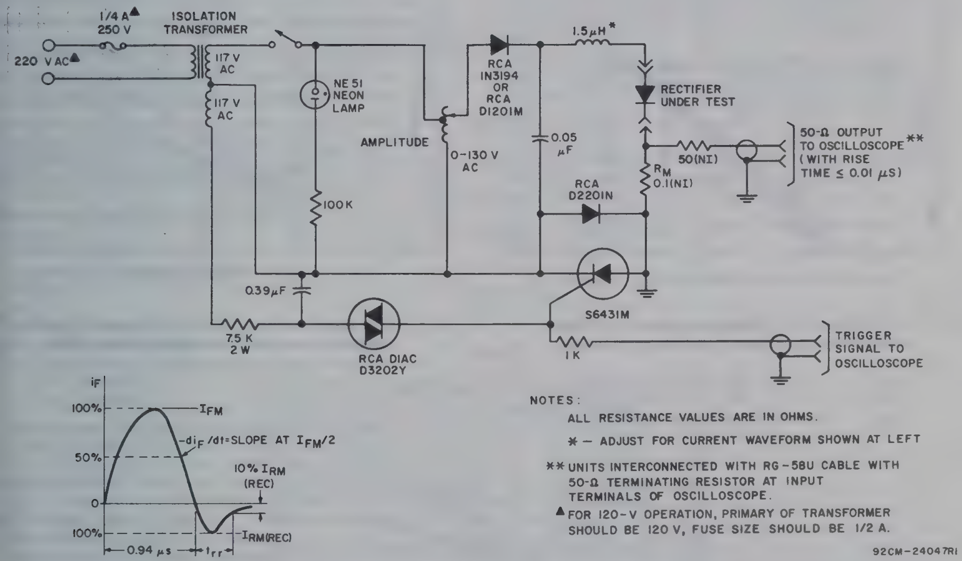


Fig. 7—Dissipation vs. repetition rate for S3702S and S3703SF


1/4 A ▲
250 V
ISOLATION TRANSFORMER
220 V AC ▲
117 V AC
117 V AC
NE 51 NEON LAMP
AMPLITUDE
0-130 V AC
100 K
RCA 1N3194 OR RCA D1201M
1.5 μH *
RECTIFIER UNDER TEST
0.05 μF
RCA D2201N
50 (NI)
RM 0.1 (NI)
50-Ω OUTPUT TO OSCILLOSCOPE ** (WITH RISE TIME ≤ 0.01 μS)
0.39 μF
7.5 K 2 W
RCA DIAC D3202Y
S6431M
1 K
TRIGGER SIGNAL TO OSCILLOSCOPE
iF
100%
50%
0
100%
IFM
-diF/dt = SLOPE AT IFM/2
10% IRM (REC)
IRM(REC)
0.94 μs
trr
92CM-24047R1

NOTES:

ALL RESISTANCE VALUES ARE IN OHMS.

* — ADJUST FOR CURRENT WAVEFORM SHOWN AT LEFT

** UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE.

▲ FOR 120-V OPERATION, PRIMARY OF TRANSFORMER SHOULD BE 120 V, FUSE SIZE SHOULD BE 1/2 A.

Fig. 8 – Oscilloscope display and test circuit for measurement of reverse-recovery time for D2101S, D2103S, and D2103SF.

TERMINAL CONNECTIONS FOR TYPES S3702S AND S3703SF

Pin 1 – Gate
Pin 2 – Cathode
Case, Mounting Flange – Anode

TERMINAL CONNECTIONS FOR TYPES D2101S, D2103S, AND D2103SF

Case, Lead No. 1 – Anode
Lead No. 2 – Cathode

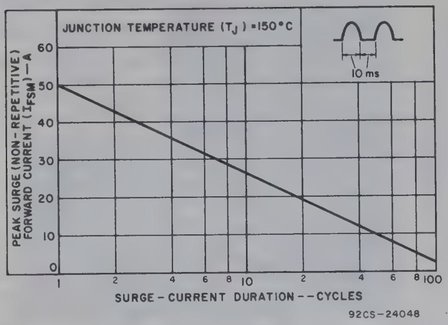


Fig. 9 — Peak surge (non-repetitive) forward current vs. surge-current duration for D2101S, D2103S, and D2103SF.

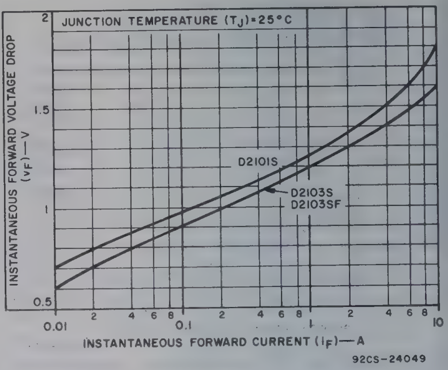


Fig. 10 — Forward-voltage drop vs. forward current for D2101S, D2103S, and D2103SF.

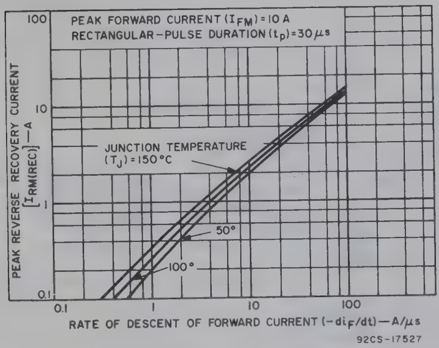


Fig. 11—Typical peak reverse recovery current vs. rate of descent of forward current for D2101S, D2103S, and D2103SF.

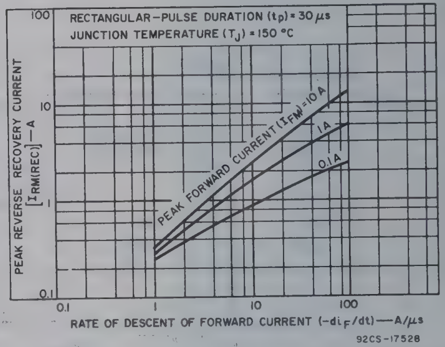


Fig. 12—Typical peak reverse recovery current vs. rate of descent of forward current for D2101S, D2103S, and D2103SF.

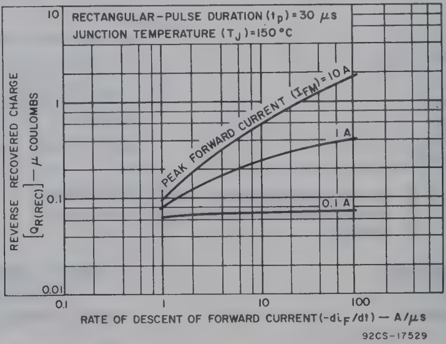


Fig. 13—Typical reverse recovered charge vs. rate of descent of forward current for D2101S, D2103S, and D2103SF.

RCA
Solid State Division

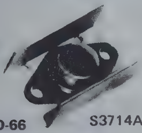
Thyristors

S3704, S3714 Series

Anode
(Case)
Cathode
Gate

S3704A,B,D,M,S

EDEC TO-66 H-1340



EDEC TO-66 S3714A,B,D,M,S
ith Integral Heat Radiator H-1470A

5-A Silicon Controlled Rectifiers

For Inverter Applications

Features

- Fast turn-off time-8 μs max.
- High di/dt and dv/dt capabilities
- Shorted-emitter gate-cathode construction . . .contains an internally diffused resistor between gate and cathode
- Center gate construction. . . .provides rapid uniform gate-current spreading for faster turn-on with substantially reduced heating effects

Voltage / Package	100 V Types	200 V Types	400 V Types	600 V Types	700 V Types
TO-66	S3704A	S3704B	S3704D	S3704M	S3704S
TO-66 with Heat Radiator	S3714A	S3714B	S3714D	S3714M	S3714S

CA-S3704 and S3714-series types are all-diffused, silicon con-olled rectifiers (reverse-blocking triode thyristors) designed for erter applications such as ultrasonics, choppers, regulated power supplies, induction heaters, cycloconverters, and fluorescent lighting. These types may be used at frequencies up to 25 kHz.

AXIMUM RATINGS, *Absolute-Maximum Values:*		S3704A S3714A	S3704B S3714B	S3704D S3714D	S3704M S3714M	S3704S S3714S	
ON-REPETITIVE PEAK REVERSE VOLTAGE:■ Gate Open	V_{RSOM}	150	300	500	700	800	V
ON-REPETITIVE PEAK OFF-STATE VOLTAGE:■ Gate Open	V_{DSOM}	150	300	500	700	800	V
EPETITIVE PEAK REVERSE VOLTAGE:■ Gate Open	V_{RROM}	100	200	400	600	700	V
EPETITIVE PEAK OFF-STATE VOLTAGE:■ Gate Open	V_{DROM}	100	200	400	600	700	V
N-STATE CURRENT: $T_C = 60^\circ C$, conduction angle = 180°:							
RMS	$I_{T(RMS)}$	5					A
Average	$I_{T(AV)}$	3.2					A
For other conditions		See Figs. 2, 3, 4					
EAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}						
For one full cycle of applied principal voltage, $T_C = 60^oC$							
60 Hz (sinusoidal)		80					A
50 Hz (sinusoidal)		65					A
For more than one full cycle of applied principal voltage		See Fig. 5					
RATE OF CHANGE OF ON-STATE CURRENT $V_D = V_{DROM}$, $I_{GT} = 50$ mA, $t_r = 0.1$ μs (See Fig. 11)	di/dt	200					A/μs
FUSING CURRENT (for SCR protection): $T_J = -40$ to 100°C, t = 1 to 8.3 ms	I^2t	25					A
GATE POWER DISSIPATION:●							
Peak Forward (for 10 μs max., See Fig. 9)	P_{GM}	13					W
Peak Reverse (for 10 μs max., See Fig. 8)	P_{RGM}	13					W
Average (averaging time = 10 ms max.)	$P_{G(AV)}$	0.5					W
TEMPERATURE RANGE:▲							
Storage	T_{stg}	−40 to 150					°C
Operating (Case)	T_C	−40 to 100					°C
PIN TEMPERATURE (During soldering): At distances ≥ 1/32 in. (0.8 mm) from seating plane for 10 s max.	T_P	225					°C

■ These values do not apply if there is a positive gate signal. Gate must be open or negatively biased.
● Any product of gate current and gate voltage which results in a gate power less than the maximum is permitted.
▲ For temperature measurement reference point, *see Dimensional Outline.*

ELECTRICAL CHARACTERISTICS

At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS			UNITS
		FOR ALL TYPES Except as Specified			
		MIN.	TYP.	MAX.	
Peak Off-State Current: (Gate open, T_C = 100°C)					
Forward Current (I_{DOM}) at $V_D = V_{DROM}$	I_{DOM}	–	0.5	3	mA
Reverse Current (I_{ROM}) at $V_R = V_{RROM}$	I_{ROM}	–	0.3	1.5	
Instantaneous On-State Voltage: i_T = 30 A (peak), T_C = 25°C	v_T	–	2.2	3	V
For other conditions			See Fig. 7		
Instantaneous Holding Current: Gate open, T_C = 25°C	i_{HO}	–	20	50	mA
Critical Rate of Rise of Off-State Voltage (See Fig. 12): $V_D = V_{DROM}$, exponential voltage rise, Gate open, T_C = 80°C	dv/dt	100	250	–	V/µs
DC Gate Trigger Current: V_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C	I_{GT}	–	15	40	mA
For other conditions			See Fig. 9		
DC Gate Trigger Voltage: V_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C	V_{GT}	–	1.8	3.5	V
For other conditions			See Fig. 9		
Gate Controlled Turn-On Time: (Delay Time + Rise Time) For $V_{DX} = V_{DROM}$, I_{GT} = 300 mA, t_r = 0.1 µs, I_T = 2 A (peak), T_C = 25°C (See Fig. 10)	t_{gt}	–	0.7	–	µs
Circuit Commutated Turn-Off Time: $V_{DX} = V_{DROM}$, i_T = 2 A, pulse duration = 50 µs, dv/dt = 100 V/µs, –di/dt = –10 A/µs, I_{GT} = 100 mA, V_{GT} = 0 V (at turn-off), T_C = 80°C (See Fig. 13)	t_q	–	4	8	µs
Thermal Resistance: Junction-to-Case	$R\theta JC$	–	4	8	°C/W
Junction-to-Ambient	$R\theta JA$	–	–	40	°C/W

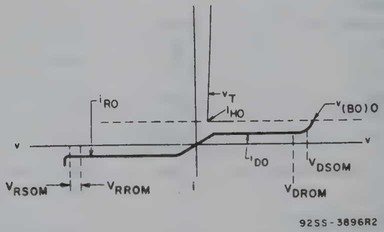
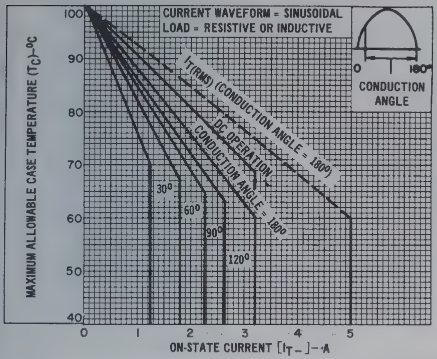
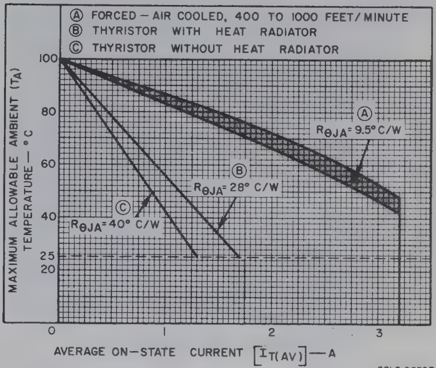


Fig. 1 – Principal voltage-current characteristic.



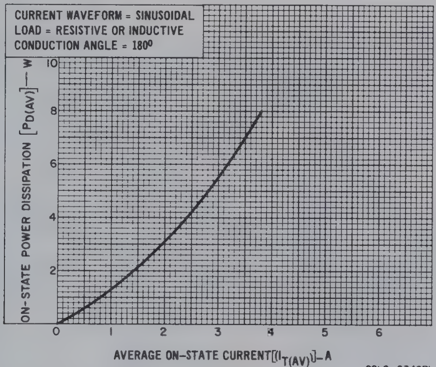
92LS–2342RI

Fig. 2 – Maximum allowable case temperature vs. on-state current.



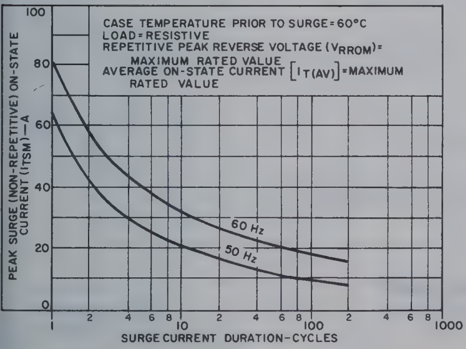
92LS-2050RI

Fig. 3 – Maximum allowable ambient temperature vs. average on-state current.



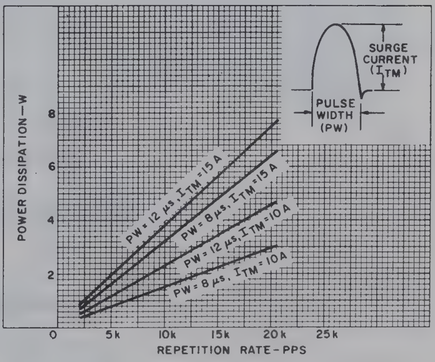
92LS–2340RI

Fig. 4 – Power dissipation vs. average on-state current.



92LS-1149R2

Fig. 5 – Peak surge on-state current vs. surge current duration.



92CS-24983

Fig. 6 – Dissipation vs. repetition rate

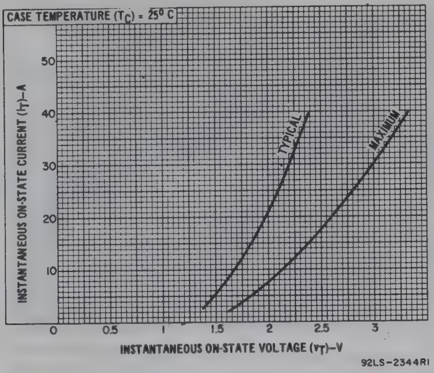


Fig. 7 – Instantaneous on-state current vs. on-state voltage.

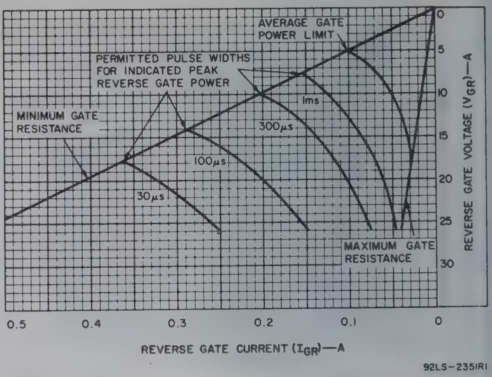


Fig. 8 – Reverse gate voltage vs. reverse gate current.

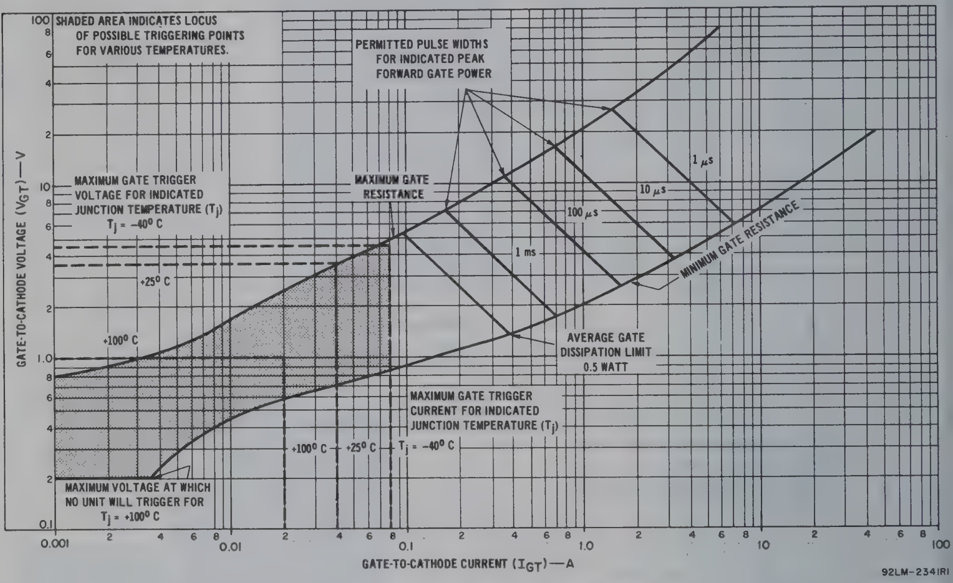


Fig. 9 – Gate trigger characteristics and limiting conditions for determination of permissible gate-trigger pulses.

TERMINAL CONNECTIONS

Pin 1 – Gate
Pin 2 – Cathode
Heat Rad., Case, Mtg. Flange – Anode

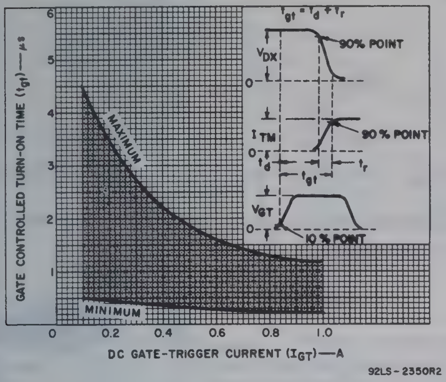


Fig. 10 – Turn-on time vs. gate-trigger current.

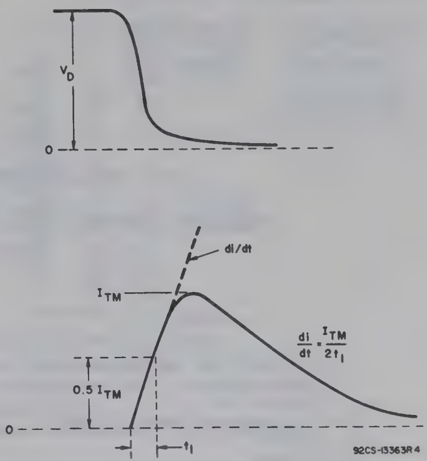

V_D
0
di/dt
I_{TM}
$\frac{di}{dt} = \frac{I_{TM}}{2t_1}$
0.5 I_{TM}
0
t_1
92CS-13363R4

Fig. 11 – Rate-of-change of on-state current with time (defining di/dt).

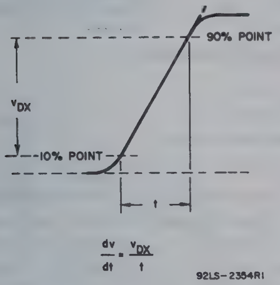

90% POINT
V_{DX}
10% POINT
t
$\frac{dv}{dt} = \frac{V_{DX}}{t}$
92LS-2354R1

Fig. 12 – Rate-of-rise of off-state voltage with time (defining dv/dt).

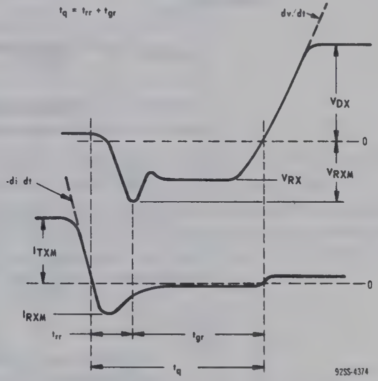

$t_q = t_{rr} + t_{gr}$
dv/dt
V_{DX}
0
V_{RX}
V_{RXM}
-di dt
I_{TXM}
0
I_{RXM}
t_{rr}
t_{gr}
t_q
92SS-4374

Fig. 13 – Relationship between off-state voltage, reverse voltage, on-state current, and reverse current showing reference points defining turn-off time (t_q).

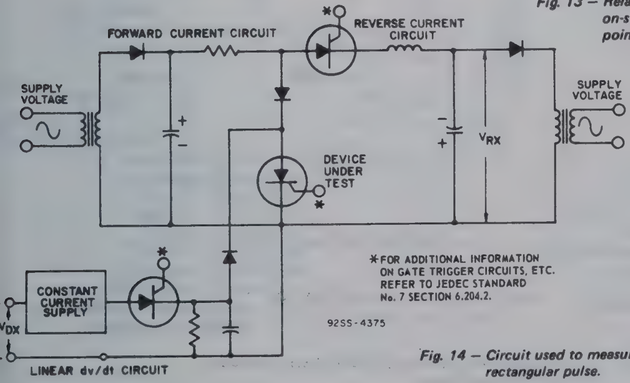
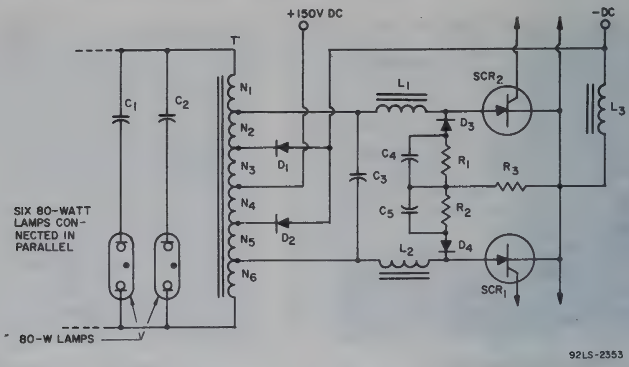

FORWARD CURRENT CIRCUIT
REVERSE CURRENT CIRCUIT
SUPPLY VOLTAGE
SUPPLY VOLTAGE
V_{RX}
DEVICE UNDER TEST
CONSTANT CURRENT SUPPLY
V_{DX}
LINEAR dv/dt CIRCUIT
*FOR ADDITIONAL INFORMATION ON GATE TRIGGER CIRCUITS, ETC. REFER TO JEDEC STANDARD No. 7 SECTION 6.204.2.
92SS-4375

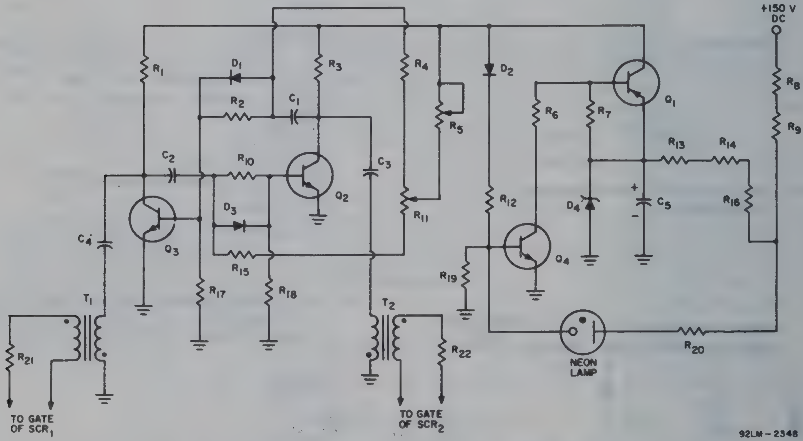
Fig. 14 – Circuit used to measure turn-off time (t_q), rectangular pulse.


+150V DC
-DC
T
N1
N2
N3
N4
N5
N6
C1
C2
C3
C4
C5
D1
D2
D3
D4
L1
L2
L3
R1
R2
R3
SCR2
SCR1
SIX 80-WATT LAMPS CONNECTED IN PARALLEL
80-W LAMPS
92LS-2353

C_1, C_2: 0.01 µF, 1200 V (Ballast Capacitors)
C_3: 0.01 µF, 600 V
C_4, C_5: 0.02 µF, 600 V
D_1, D_2: Fast-Recovery Diodes, 6 A, 600 V
D_3, D_4: 1N574
L_1, L_2: 32 µH
L_3: 131 Turns of No.15 Magnet Wire on Arnold Engineering Core No.A4-04117, or equivalent

R_1, R_2: 1.2 kΩ, 5 watt
R_3: 200 Ω, 10 watt
T: Core, 8 pieces of Indiana General No. CF-602 Material 05, or equivalent. Cross Section, 8 cm^2
N_1, N_6 – 30 Turns of No.18 Magnet Wire
N_2, N_5 – 13 Turns of No.18 Magnet Wire, 2 Strands
N_3, N_4 – 52 Turns of No.18 Magnet Wire, 2 Strands

Fig. 15 – Typical inverter circuit for 500-W, 8-kHz fluorescent-light control.


+150 V DC
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22
C1
C2
C3
C4
C5
D1
D2
D3
D4
Q1
Q2
Q3
Q4
T1
T2
NEON LAMP
TO GATE OF SCR1
TO GATE OF SCR2
92LM-2348

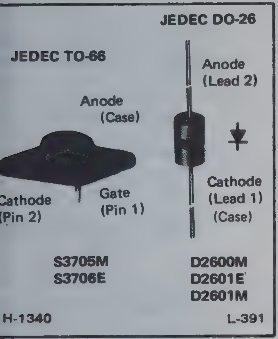
Q_1: RCA-40438
Q_2, Q_3, Q_4: RCA-2N3053
C_1, C_2: 0.003 µF, 100 V
C_3, C_4: 0.02 µF, 100 V
C_5: 25 µF, 25 V, electrolytic
D_1, D_2, D_3: Transitron type T1G, or equivalent
D_4: Motorola type 1M20Z10, or equivalent
Neon Lamp: GE type NE-83, or equivalent
R_1, R_3: 1 kΩ, 1/4 watt
R_2, R_{10}: 180 kΩ, 1/4 watt

R_4, R_{12}, R_{15}, R_{17}, R_{18}: 22 kΩ, 1/4 watt
R_5, R_{11}: 10 kΩ potentiometer
R_6: 10 kΩ, 1/4 watt
R_7: 1.5 kΩ, 1/4 watt
R_8, R_9, R_{13}, R_{14}, R_{16}: 680 Ω, 2 watts
R_{19}: 5.6 kΩ, 1/4 watt
R_{20}: 33 kΩ, 1/4 watt
R_{21}, R_{22}: 10 Ω, 1/4 watt
T_1, T_2: Sprague Pulse Transformer type 42Z109, or equivalent

Fig. 16 – Typical trigger-pulse generator for 500-W, 8-kHz fluorescent-light control inverter circuit.

RCA
Solid State Division

Thyristors/Rectifiers
S3705M D2600M S3706E D2601E D2601M


JEDEC DO-26
JEDEC TO-66
Anode (Lead 2)
Anode (Case)
Cathode (Lead 1) (Case)
Cathode (Pin 2)
Gate (Pin 1)
S3705M
S3706E
D2600M
D2601E
D2601M
H-1340
L-391

SCR's and Rectifiers for Horizontal-Deflection Circuits

For Large-Screen Color TV

Features:

- Ability to handle high beam current; average 1.6 mA dc
- Ability to supply as much as 5 mJ of stored energy to the deflection yoke, which is sufficient for 29-mm-neck and 36.5-mm-neck picture tubes operated at 29 kV (nominal value)
- Highly reliable circuit which can also be used as a low-voltage power supply

Package \ Voltage	600 V Types	500 V Types
TO-66	S3705M	S3706E
DO-26	D2600M, D2601M	D2601E

hese RCA types are designed for use in a horizontal output rcuit such as that shown in Fig. 1.

he S3705M silicon controlled rectifier and the D2601M icon rectifier are designed to act as a bipolar switch that ntrols horizontal yoke current during the beam trace interval. he S3706E silicon controlled rectifier and the D2601E silicon rectifier act as the commutating switch to initiate trace-retrace switching and control yoke current during retrace.

The D2600M silicon rectifier may be used as a clamp to protect the circuit components from excessively high transient voltages which may be generated as a result of arcing in the picture tube or in a high-voltage rectifier tube.

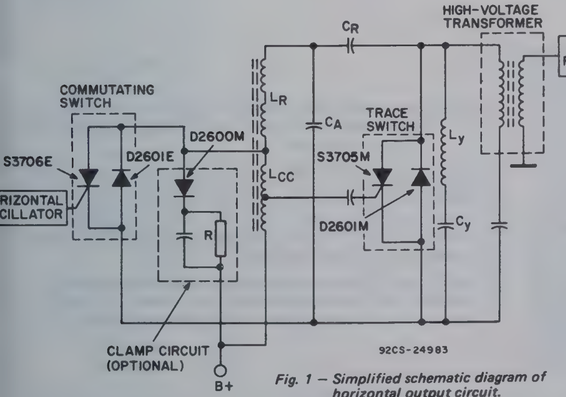

HIGH-VOLTAGE TRANSFORMER
CR
HV RECT.
TO PICTURE TUBE
COMMUTATING SWITCH
LR
CA
TRACE SWITCH
Ly
D2600M
S3706E
D2601E
S3705M
LCC
RIZONTAL CILLATOR
R
D2601M
Cy
CLAMP CIRCUIT (OPTIONAL)
B+
92CS-24983

Fig. 1 – Simplified schematic diagram of horizontal output circuit.

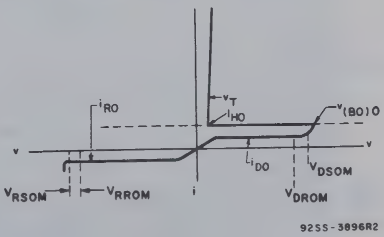


Fig.2 – Principal voltage-current characteristic for S3705M and S3706E.

SILICON CONTROLLED RECTIFIERS

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		S3705M TRACE SCR	S3706E COMMUTATING SCR	
NON-REPETITIVE PEAK OFF-STATE VOLTAGE:●				
Gate Open	V_{DSOM}	700*	600*	V
REPETITIVE PEAK REVERSE VOLTAGE:●				
Gate Open	V_{RROM}	25	25	V
REPETITIVE PEAK OFF-STATE VOLTAGE:●				
Gate Open	V_{DROM}	600	500	V
ON-STATE CURRENT:				
$T_C = 60^\circ C$, 60 Hz sine wave, conduction angle = 180°:				
RMS	$I_{T(RMS)}$	5	5	A
Average DC	$I_{T(AV)}$	3.2	3.2	A
PEAK SURGE (NON–REPETITIVE) ON-STATE CURRENT:	I_{TSM}			
For one full cycle of applied principal voltage				
60 Hz (sinusoidal), $T_C = 60^\circ C$		80	80	A
50 Hz (sinusoidal), $T_C = 60^\circ C$		65	65	A
For one-half sine wave, 3 ms pulse width		150	150	A
RATE OF CHANGE OF ON-STATE CURRENT:				
$V_D = V_{DROM}$, $I_{GT} = 50$ mA, $t_r = 0.1\ \mu s$	di/dt	200	200	A/μs
FUSING CURRENT (for SCR protection):				
$T_J = -40$ to $80^\circ C$, t = 1 to 10 ms	I^2t	20	20	A^2s
GATE POWER DISSIPATION:■	P_{GM}			
Peak (forward or reverse) for 10 μs duration, max.				
negative gate bias = −35 V (S3705M)		25	–	W
= −10 V (S3706E)		–	25	W
TEMPERATURE RANGE:▲				
Storage	T_{stg}	−40 to 150	−40 to 150	°C
Operating (Case)	T_C	−40 to 80	−40 to 80	°C
PIN TEMPERATURE (During soldering):				
At distances ≥ 1/32 in. (0.8 mm) from seating plane for 10 s max.	T_P	225	225	°C

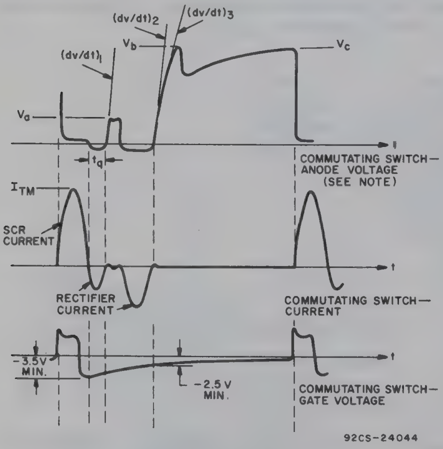
---

*Protection against transients above these values induced by arcing or other causes must be provided.

●These values do not apply if there is a positive gate signal. Gate must be open or negatively biased.

■Any product of gate current and gate voltage which results in a gate power less than the maximum is permitted, provided that the maximum reverse gate bias (as specified) is not exceeded.

▲For temperature measurement reference point, see Dimensional Outline.


(dv/dt)2
(dv/dt)3
Vb
Vc
(dv/dt)1
Va
tq
t
COMMUTATING SWITCH—ANODE VOLTAGE (SEE NOTE)
ITM
SCR CURRENT
t
RECTIFIER CURRENT
COMMUTATING SWITCH—CURRENT
−3.5V MIN.
t
−2.5 V MIN.
COMMUTATING SWITCH—GATE VOLTAGE
92CS-24044

NOTE: "Commutating Switch-Anode Voltage" oscilloscope display has been modified graphically to show the measurement points of dv/dt more effectively.

I_{TM} = 15 A, V_a = 100 V max., V_b = 250 V max., V_c = 400. Gate voltage = 12 V positive from 15 V supply. Gate current should rise to 100 mA within 0.2 μs. Minimum duration of gate current pulse = 3 μs. Minimum amplitude of gate current pulse = 200 mA. Negative gate bias at turn-off = −3.5 V minimum, negative gate bias at 2nd reapplied voltage $(dv/dt)_2$ = −2.5 V minimum.

$(dv/dt)_1$ = 400 V/μs (measured tangent to waveform at 0.8 of V_a)
$(dv/dt)_2$ = 1000 V/μs (measured tangent to waveform at 0.3 of V_b)
$(dv/dt)_3$ = 700 V/μs (measured tangent to waveform at 0.8 of V_b)

Fig.3 – Oscilloscope display of commutating switching (S3706E) showing circuit-commutated turn-off time (tq).

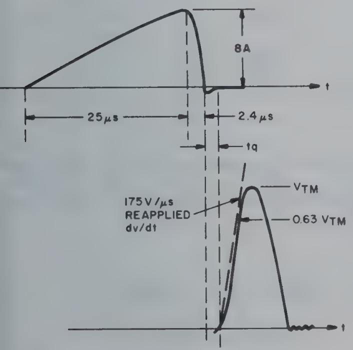
SILICON CONTROLLED RECTIFIERS

ELECTRICAL CHARACTERISTICS

At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS				UNITS
		S3705M TRACE SCR		S3706E COMMUTATING SCR		
		TYP.	MAX.	TYP.	MAX.	
Peak Forward Off-State Current: Gate open, $V_D = V_{DROM}$ $T_C = 85°C$ . .	I_{DOM}	0.5	1.5	0.5	1.5	mA
Instantaneous On-State Voltage: i_T = 30 A (peak), $T_C = 25°C$	v_T	2.2	3	2.2	3	V
Critical Rate of Rise of Off-State Voltage: $V_D = V_{DROM}$, exponential voltage rise, $T_C = 70°C$	dv/dt	175 (min.) (See Fig.4)		1000 (min.) $(dv/dt)_2$ (See Fig.3)		V/µs
DC Gate Trigger Current: V_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C	I_{GT}	15	32	15	45	mA
DC Gate Trigger Voltage: V_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C	V_{GT}	1.8	4	1.8	4	V
Circuit Commutated Turn-Off Time:◆ T_C = 70°C, minimum negative gate bias during turn-off time = −20 V (S3705M) and −2.5 V (S3706E), rate of reapplied voltage (dv/dt) = 175 V/µs (See Fig. 4) . . . . = 400 V/µs (See Fig. 3	t_q	– –	2.5 –	– –	– 4.5	µs µs
Thermal Resistance, Junction-to-Case . . .	$R_{\theta JC}$	–	4	–	4	°C/W

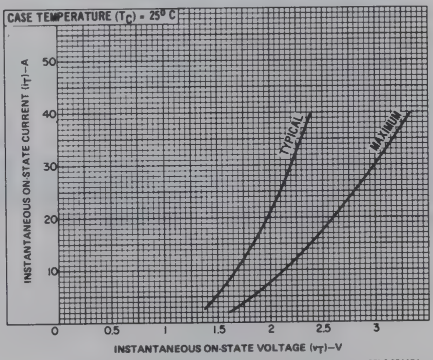
◆ This parameter, the sum of reverse recovery time and gate recovery time, is measured from the zero crossing of current to the start of the reapplied voltage. Knowledge of the current, the reapplied voltage, and the case temperature is necessary when measuring t_q. In the worst conditions (high line, zero-beam, off-frequency, minimum auxiliary load, etc.), turn-off time must not fall below the given values. Turn-off time increases with temperature, therfore, case temperature must not exceed 70°C. See Figs. 3 and 4.



I_{TM} = 8 A, $V_{TM} = V_{DROM}$, reapplied dv/dt = 175 V/µs (measured from 0 to 0.63 of V_{TM}), negative gate voltage source = −24 V, source impedance = 15 Ω.

92CS-24045

– Oscilloscope display of trace switching (S3705M) showing circuit-commutating turn-off time (tq).



92LS-2344R1

Fig.5 – Instantaneous on-state current vs. on-state voltage for S3705M and S3706E.

SILICON RECTIFIERS

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		D2601M TRACE	D2601E COMMUTATING	D2600M CLAMP	
REVERSE VOLTAGE:**					
Repetitive Peak	V_{RRM}	600	500	600	V
Non-Repetitive Peak●●	V_{RSM}	700	600	700	V
FORWARD CURRENT (operating in 15 kHz deflection circuit):					
RMS	$I_{F(RMS)}$	1.9■■	1.6■■	0.5**	A
Peak Surge (Non-Repetitive)●●	I_{FSM}	70▲▲	70▲▲	30 ▲▲	A
Peak (Repetitive)	I_{FRM}	6.5	6	0.5	A
TEMPERATURE RANGE					
Storage	T_{stg}		−30 to 150		°C
Operating (Case)	T_C		−30 to 80		°C
LEAD TEMPERATURE (During Soldering):					
Measured 1/8 in. (3.17 mm) from case for 10 s maximum	T_L		225		°C

** For ambient temperatures up to 45°C.

●● For a maximum of 3 pulses, each less than 10 µs duration, during any 64-µs period.

■■ Maximum current rating applies only if the rectifier is properly mounted to maintain junction temperature below 150°C.

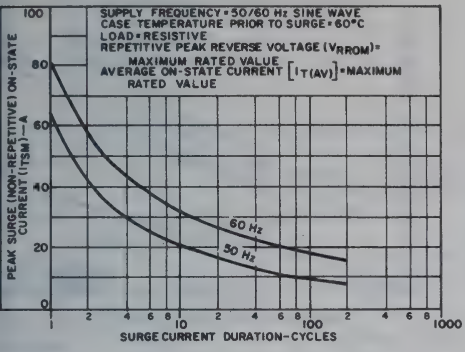
▲▲ See Fig.9 for I_{FSM} value for 50 and 60 Hz operation.

SILICON RECTIFIERS

ELECTRICAL CHARACTERISTICS

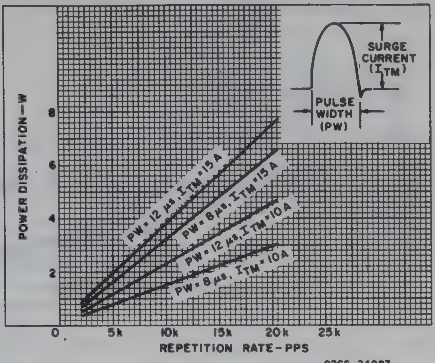
CHARACTERISTIC	SYMBOL	LIMITS		UNITS
		D2601M TRACE D2601E COMMUT	D2600M CLAMP	
		MAXIMUM	MAXIMUM	
Reverse Current: *Static* For V_{RRM} = max. rated value, $I_F = 0$, $T_C = 25°C$ For $V_R = 500$ V, $T_C = 100°C$	I_{RM}	10 250	10 250	µA
Instantaneous Forward Voltage Drop: At $i_F = 4$ A, $T_A = 25°C$	v_F	1.9	2	V
Reverse Recovery Time: For circuit shown in Fig. 8: At $I_{FM} = 20$ A, $-di_F/dt = -20$ A/µs, pulse duration = 2.8 µs, $T_C = 25°C$	t_{rr}	0.5	0.7	µs
In Tektronix type "S" plug-in unit (or equivalent): At $I_F = 20$ mA, $I_R = 1$ mA, $T_C = 25°C$		1.2	1.5	
Peak Forward Voltage Drop (at turn-on): In Tektronic type "S" plug-in unit (or equivalent): At $I_F = 20$ mA, $T_C = 25°C$	$V_{F(pk)}$	5	6	V
Thermal Resistance (Junction-to-Lead)◆ (See Fig.14)	$R_{\theta JL}$	45	45	°C/W

◆ Measured on anode lead 1/8 in. (3.18 mm) from case.



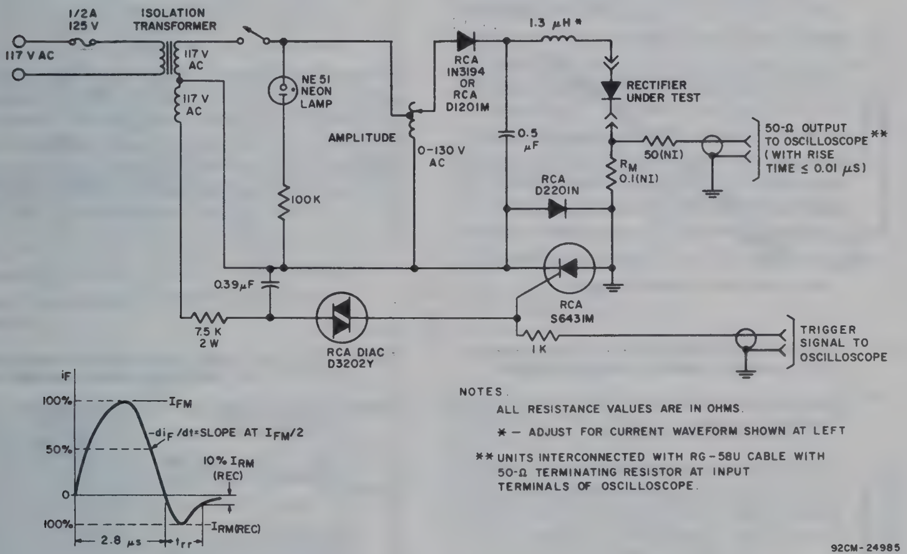
92LS-1149R2

Fig.6 — Peak surge on-state current vs. surge current duration for S3705M and S3706E.



92CS-24983

Fig.7 — Dissipation vs. repetition rate for S3705M and S3706E.


1/2A 125 V
ISOLATION TRANSFORMER
117 V AC
117 V AC
117 V AC
NE 51 NEON LAMP
AMPLITUDE
0-130 V AC
100K
RCA 1N3194 OR RCA D1201M
1.3 µH *
RECTIFIER UNDER TEST
0.5 µF
50-Ω OUTPUT TO OSCILLOSCOPE ** (WITH RISE TIME ≤ 0.01 µS)
50(NI)
RM 0.1(NI)
RCA D2201N
0.39µF
7.5 K 2 W
RCA DIAC D3202Y
RCA S6431M
1 K
TRIGGER SIGNAL TO OSCILLOSCOPE
iF
100%
50%
0
100%
IFM
-diF/dt=SLOPE AT IFM/2
10% IRM (REC)
IRM(REC)
2.8 µs
trr

NOTES.

ALL RESISTANCE VALUES ARE IN OHMS.

* — ADJUST FOR CURRENT WAVEFORM SHOWN AT LEFT

** UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE.

92CM-24985

Fig. 8 — Oscilloscope display and test circuit for measurement of reverse-recovery time for D2600M, D2601E, and D2601M.

TERMINAL CONNECTIONS FOR TYPES S3705M AND S3706E

Pin 1 — Gate
Pin 2 — Cathode
Case, Mounting Flange — Anode

TERMINAL CONNECTIONS FOR TYPES D2600M, D2601E, AND D2601M

Case, Lead 1 — Cathode
Lead 2 — Anode

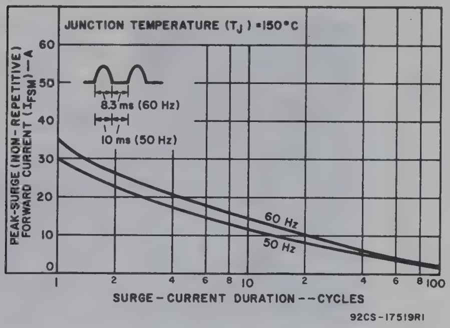


Fig.9 – Peak-surge (non-repetitive) forward current vs. surge-current duration for D2600M, D2601E, and D2601M;

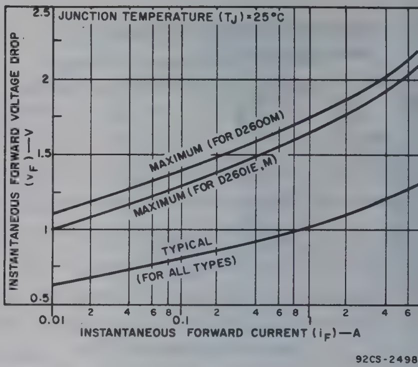


Fig.10 – Forward-voltage drop vs. forward current for D2600M, D2601E, and D2601M.

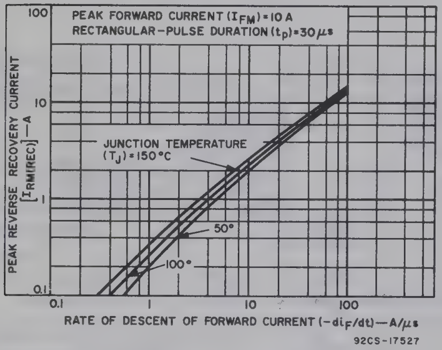


Fig.11 – Typical peak reverse-recovery current vs. rate of descent of forward current for D2600M, D2601E, and D2601M.

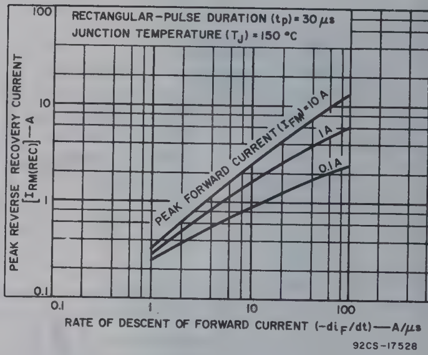


Fig.12 – Typical peak reverse-recovery current vs. rate of descen forward-current for D2600M, D2601E, and D2601M.

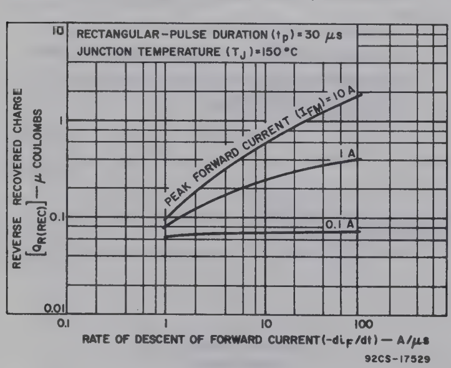


Fig.13 – Typical reverse-recovered charge vs. rate of descent of forward current for D2600M, D2601E, and D2601M.

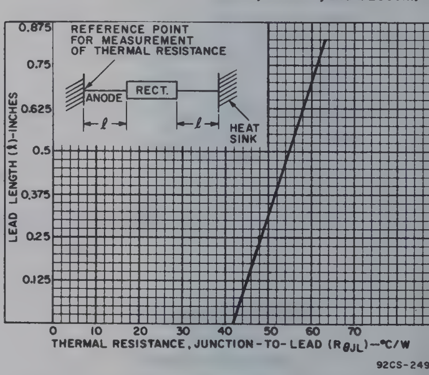
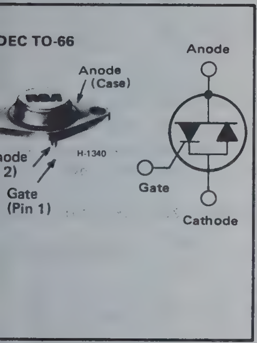


Fig.14 – Junction-to-lead thermal resistance vs. lead length f D2600M, D2601E, and D2601M.

RCA
Solid State Division

Thyristors / Rectifiers

S3800 Series


DEC TO-66
Anode (Case)
ode
2)
Gate
(Pin 1)
H-1340
Anode
Gate
Cathode

ITR's (Integrated Thyristor/Rectifiers)

Power Integrated Circuits for Color and Monochrome TV Horizontal Deflection

Package \ Voltage	400 V Type	500 V Type	550 V Type	600 V Type	650 V Type	700 V Type	750 V Type
TO-66	S3800D (41023)	S3800E (41019)	S3800EF (41022)	S3800M (41021)	S3800MF (41018)	S3800S (41020)	S3800SF (41017)

Numbers in parentheses are former RCA type numbers.

S3800 series are all-diffused power integrated circuits incorporate a silicon controlled rectifier and a silicon ier on a common pellet. S3800SF, S3800MF, and 0E are used as bipolar switches to control horizontal current during the beam trace interval; S3800S, S3800M, 0EF, and S3800D are used as commutating switches to te trace-retrace switching.

Application Features:

- Operation from supply voltages between 150 and 270 V (nominal)
- Ability to handle high beam current (average 1.6 mA dc)
- Ability to supply as much as 7 mJ of stored energy to the deflection yoke, which is sufficient for 29-mm-neck picture tubes and 35-mm-neck picture tubes operated at 25 kV (nominal value)
- Highly reliable circuit that can also be used as a low-voltage power supply

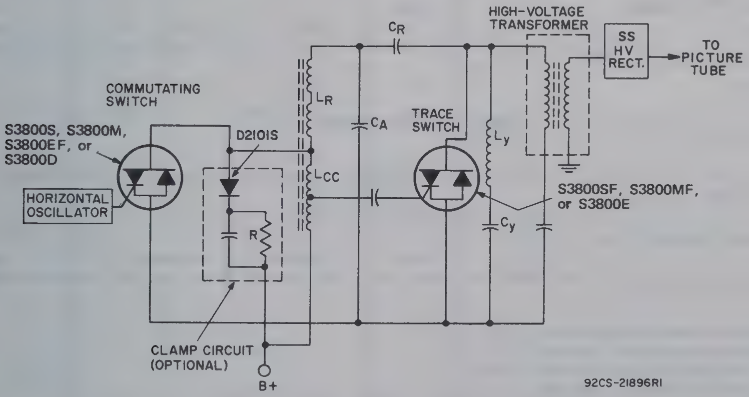

HIGH-VOLTAGE TRANSFORMER
C_R
SS HV RECT.
TO PICTURE TUBE
COMMUTATING SWITCH
L_R
C_A
TRACE SWITCH
S3800S, S3800M, S3800EF, or S3800D
D2101S
L_y
L_CC
HORIZONTAL OSCILLATOR
S3800SF, S3800MF, or S3800E
R
C_y
CLAMP CIRCUIT (OPTIONAL)
B+
92CS-21896RI

Fig. 1—Simplified schematic diagram of horizontal output circuit.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

	Symbol	S3800SF	S3800MF	S3800E	S3800S	S3800M	S3800EF	S3800D	
Non-Repetitive Peak Off-State Voltage:									
Gate open	V_{DSOM}	800*	700*	550*	750*	650*	600*	500*	V
Repetitive Peak Off-State Voltage:									
Gate open	V_{DROM}								
T_C = 80°C		750	650	500	700	600	550	400	V
Repetitive Peak Reverse Voltage:									
Gate open	V_{RROM}	0	0	0	0	0	0	0	V
On-State Current:									
T_C = 60°C, 50 Hz sine wave, conduction angle = 180°:									
Average DC	$I_{T(AV)}$	3.2	3.2	3.2	3.2	3.2	3.2	3.2	A
RMS	$I_{T(RMS)}$	5	5	5	5	5	5	5	A
Peak Surge (Non-Repetitive):									
For one cycle of applied voltage, 50 Hz	I_{TSM}	50	50	50	50	50	50	50	A
Critical Rate of Rise of On-State Current:									
For V_D = V_{DROM} rated value, I_{GT} = 50 mA, 0.1 µs rise time	di/dt	200	200	200	200	200	200	200	A/µs
Fusing Current (for ITR protection):									
T_J = −40 to 80°C, t = 1 to 8.3 ms	I^2t	6							A^2s
Gate Power Dissipation:									
Peak (forward or reverse) for 10 µs duration; max. reverse gate bias = −35 V for S3800SF, MF, E; −8 V for S3800S, M, EF, D	P_{GM}	25	25	25	25	25	25	25	W
Temperature Range■:									
Storage	T_{stg}	−40 to 150							°C
Operating (case)	T_C	−40 to 80							°C

---

*Protection against transients above this value must be provided. Transients generated by arcing may persist for as long as 10 cycles.

■Temperature measurement point is shown on the DIMENSIONAL OUTLINE.

ELECTRICAL CHARACTERISTICS, *At Maximum Ratings and at Indicated Case Temperature (T_C)*

CHARACTERISTIC	SYMBOL	LIMITS				UNITS
		S3800SF, S3800MF, S3800E		S3800S, S3800M, S3800EF, S3800D		
		TYP.	MAX.	TYP.	MAX.	
Peak Forward Off-State Current: Gate open, V_{DO} = Rated V_{DROM} T_C = 85°C	I_{DOM}	0.5	1.5	0.5	1.5	mA
Instantaneous On-State Voltage: T_C = 25°C SCR, I_T = 30 A	V_T	2.2	3	2.2	3	V
Rectifier, I_F = 3 A	V_F	–	1.6	–	1.6	
DC Gate Trigger Current: T_C = 25°C	I_{GT}	15	40	15	45	mA
DC Gate Trigger Voltage: T_C = 25°C	V_{GT}	1.8	4	1.8	4	V
Critical Rate of Rise of Off-State Voltage: T_C = 70°C	dv/dt	850(MIN.)▲		850(MIN.)▲		V/µs
Circuit-Commutated Turn-Off Time†: T_C = 70°C Minimum negative bias during turn-off time = −20 V, rate of reapplied voltage (dv/dt) = 175 V/µs	t_q	–	2.4	–	–	µs
Minimum negative bias during turn-off time = −2.5 V, rate of reapplied voltage (dv/dt) = 400 V/µs		–	–	–	4.2	
Thermal Resistance: Junction-to-Case	$R_{\theta JC}$	–	4	–	4	°C/W

▲ Up to 500 V max. (with negative bias from −2.5 V to −4.0 V).

† This parameter, the sum of reverse recovery time and gate recovery time, is measured from the zero crossing of current to the start of the reapplied voltage. Knowledge of the current, the reapplied voltage, and the case temperature is necessary when measuring t_q. In the worst conditions (high line, zero-beam, off-frequency, minimum auxiliary load, etc.), turn-off time must not fall below the given values. Turn-off time increases with temperature; therefore, case temperature must not exceed 70°C.

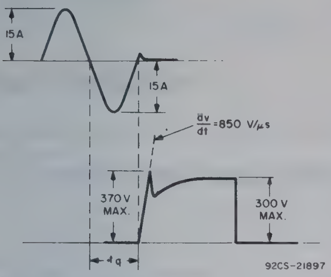
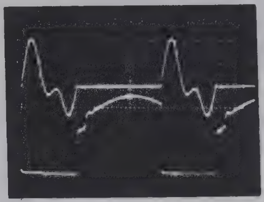

15 A
15 A
$\frac{dv}{dt}$ = 850 V/µs
370 V MAX.
300 V MAX.
t_q
92CS-21897

Fig. 2— Circuit-commutated turn-off time in commutating ITR.



UPPER TRACE: CURRENT (5 A/CM)
LOWER TRACE: VOLTAGE (100 V/CM)

92CS-21073R1

Fig. 3— Typical deflection-circuit waveforms for commutating ITR.

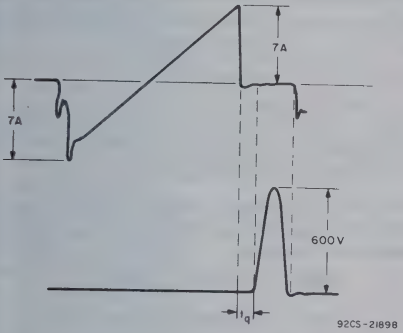
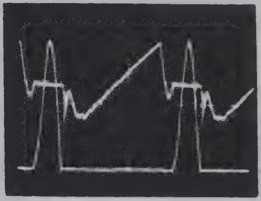

7 A
7 A
600 V
t_q
92CS-21898

Fig. 4— Circuit-commutated turn-off time in trace ITR.



UPPER TRACE: CURRENT (2 A/CM)
LOWER TRACE: VOLTAGE (100 V/CM)

92CS-21072R1

Fig. 5— Typical deflection-circuit waveforms for trace ITR.

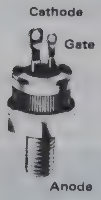
TERMINAL CONNECTIONS

Pin 1 — Gate
Pin 2 — Cathode
Case, Mounting Flange — Anode

RCA
Solid State
Division

Thyristors

S5210 Series



Stud H-1612

10-A Silicon Controlled Rectifiers

For Inverter Applications

Features:

- Fast turn-off time — 8 μs max.
- High di/dt and dv/dt capabilities
- Shorted-emitter gate-cathode construction . . . contains an internally diffused resistor between gate and cathode
- Low thermal resistance
- Center gate construction . . . provides rapid uniform gate-current spreading f faster turn-on with substantially reduc heating effects

Package \ Voltage	200 V	400 V	600 V
Stud	S5210B	S5210D	S5210M

RCA-S5210-series types are all-diffused, silicon controlled rectifiers designed for high-frequency power-switching applications such as inverters, switching regulators, and hig current pulse applications. These types may be used frequencies up to 25 kHz.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		S5210B	S5210D	S5210M	
NON-REPETITIVE PEAK REVERSE VOLTAGE:• Gate Open	V_{RSOM}	200	400	600	V
NON-REPETITIVE PEAK OFF-STATE VOLTAGE:• Gate Open	V_{DSOM}	250	500	700	V
REPETITIVE PEAK REVERSE VOLTAGE:• Gate Open	V_{RROM}	200	400	600	V
REPETITIVE PEAK OFF-STATE VOLTAGE:• Gate Open	V_{DROM}	200	400	600	V
ON-STATE CURRENT: T_C = 85°C, conduction angle = 180°:					
RMS	$I_{T(RMS)}$		← 10 →		A
Average	$I_{T(AV)}$		← 6.3 →		A
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT: For one full cycle of applied principal voltage 60 Hz (sinusoidal)	I_{TSM}		← 90 →		A
RATE OF CHANGE OF ON-STATE CURRENT: $V_D = V_{DROM}$, I_{GT} = 50 mA, t_r = 0.1 μs (See Fig. 6)	di/dt		← 200 →		A/μ
FUSING CURRENT (for SCR protection): T_J = −40 to 100°C, t = 1 to 8.3 ms	i^2t		← 35 →		A^2
GATE POWER DISSIPATION:■					
Peak Forward (for 10 μs max.)	P_{GM}		← 13 →		W
Average (averaging time = 10 ms max.)	$P_{G(AV)}$		← 0.5 →		W
TEMPERATURE RANGE:▲					
Storage	T_{stg}		← −40 to 150 →		°
Operating (Case)	T_C		← −40 to 100 →		°
TERMINAL TEMPERATURE (During Soldering): For 10 s max. (terminals and case)	T_T		← 225 →		°
STUD TORQUE:	τ_s				
Recommended			← 35 →		in-lb
Maximum (DO NOT EXCEED)			← 50 →		in-lb

• These values do not apply if there is a positive gate signal. Gate must be open or negatively biased.

■ Any product of gate current and gate voltage which results in a gate power less than the maximum is permitted.

▲ For temperature measurement reference point, see Dimensional Outline.

LECTRICAL CHARACTERISTICS

t Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS FOR ALL TYPES Except as Specified			UNITS
		Min.	Typ.	Max.	
eak Off-State Current: Gate open, $T_C = 100^oC$)					
Forward Current (I_{DOM}) at $V_D = V_{DROM}$	I_{DOM}	–	–	3	mA
Reverse Current (I_{ROM}) at $V_R = V_{RROM}$	I_{ROM}	–	–	3	
stantaneous On-State Voltage: i_T = 30 A (peak), $T_C = 25^oC$	v_T	–	2.2	3	V
For other conditions		See Fig. 4			
stantaneous Holding Current: Gate open, $T_C = 25^oC$	i_{HO}	–	20	50	mA
ritical Rate of Rise of Off-State Voltage (See Fig. 7): $V_D = V_{DROM}$, exponential voltage rise, Gate open, $T_C = 80^oC$	dv/dt	100	250	–	V/μs
C Gate Trigger Current: V_D = 12 V (dc), R_L = 30 Ω, $T_C = 25^oC$	I_{GT}	–	15	40	mA
C Gate Trigger Voltage: V_D = 12 V (dc), R_L = 30 Ω, $T_C = 25^oC$	V_{GT}	–	1.8	3.5	V
ate Controlled Turn-On Time: (Delay Time + Rise Time) For $V_{DX} = V_{DROM}$, I_{GT} = 300 mA, t_r = 0.1 μs, I_T = 2 A (peak), $T_C = 25^oC$ (See Fig. 5)	t_{gt}	–	0.7	–	μs
ircuit Commutated Turn-Off Time: $V_{DX} = V_{DROM}$, i_T = 10 A, pulse duration = 50 μs, dv/dt = 100 V/μs, –di/dt = –10 A/μs, I_{GT} = 100 mA, V_{GT} = 0 V (at turn-off), $T_C = 80^oC$ (See Figs. 8 & 9)	t_q	–	–	8	μs
hermal Resistance, Junction-to-Case	$R_{\theta JC}$	–	–	1.5	°C/W

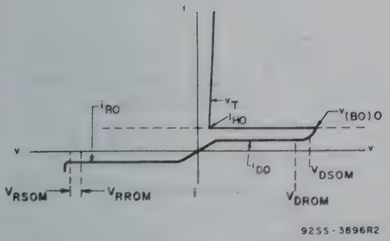


Fig. 1— Principal voltage-current characteristic.

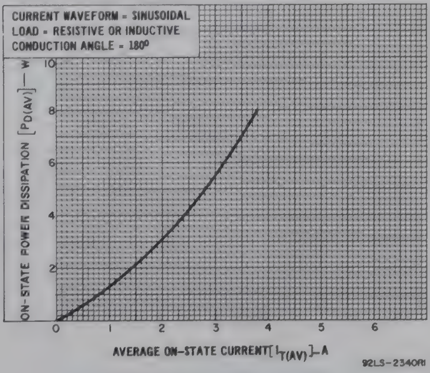


Fig. 2— Power dissipation vs. average on-state current.

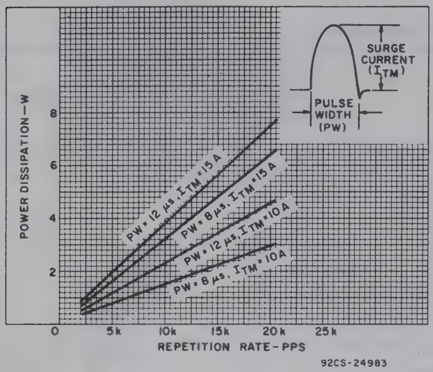


Fig. 3— Dissipation vs. repetition rate.

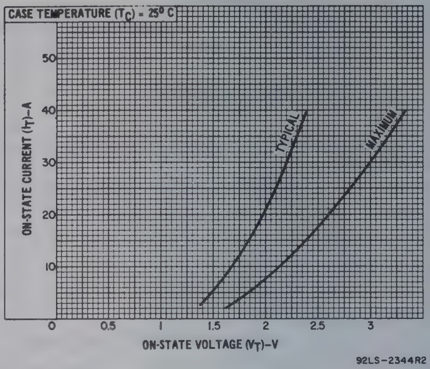


Fig. 4— Instantaneous on-state current vs. on-state voltage.

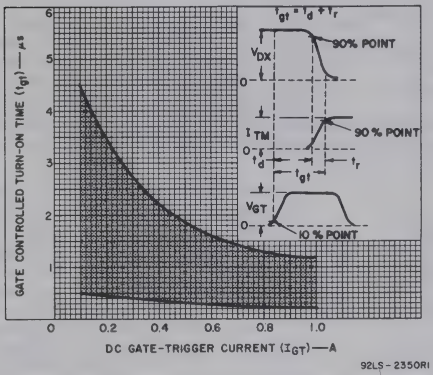


Fig. 5— Turn-on time vs. gate-trigger current.

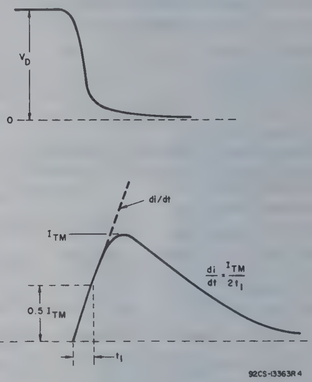

V_D
0
di/dt
I_{TM}
$\frac{di}{dt} = \frac{I_{TM}}{2t_1}$
0.5 I_{TM}
0
t_1
92CS-13363R4

Fig. 6— Rate-of-change of on-state current with time (defining di/dt).

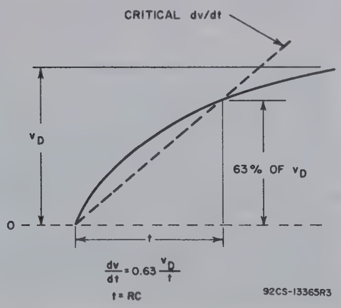

CRITICAL dv/dt
v_D
63 % OF v_D
0
t
$\frac{dv}{dt} = 0.63 \frac{v_D}{t}$
t = RC
92CS-13365R3

Fig. 7— Rate-of-rise of off-state voltage with time (defining dv/dt).

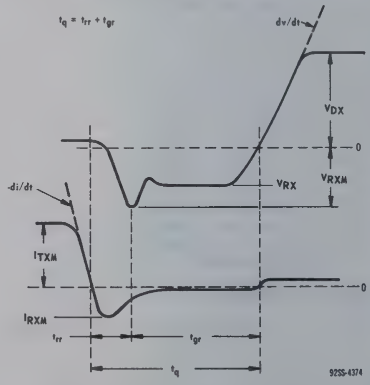

$t_q = t_{rr} + t_{gr}$
dv/dt
V_{DX}
0
V_{RXM}
V_{RX}
-di/dt
I_{TXM}
0
I_{RXM}
t_{rr}
t_{gr}
t_q
92SS-4374

Fig. 8— Relationship between off-state voltage, reverse voltage, on-state current, and reverse current showing reference points defining turn-off time (t_q).

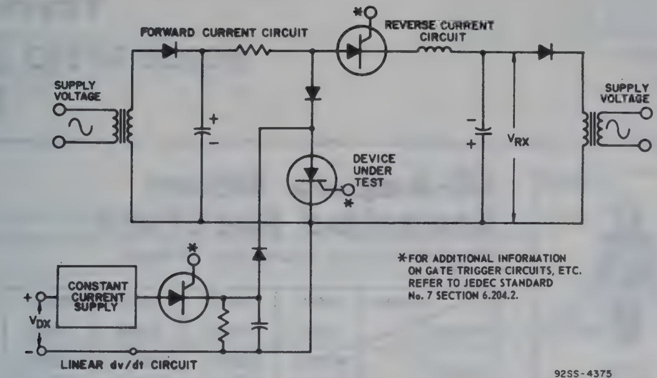

FORWARD CURRENT CIRCUIT
REVERSE CURRENT CIRCUIT
SUPPLY VOLTAGE
SUPPLY VOLTAGE
DEVICE UNDER TEST
V_{RX}
CONSTANT CURRENT SUPPLY
V_{DX}
LINEAR dv/dt CIRCUIT
*FOR ADDITIONAL INFORMATION ON GATE TRIGGER CIRCUITS, ETC. REFER TO JEDEC STANDARD No. 7 SECTION 6.204.2.
92SS-4375

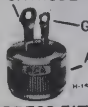
Fig. 9— Circuit used to measure turn-off time (t_q), rectangular pulse.

TERMINAL CONNECTIONS

No. 1 — Gate
No. 2 — Cathode
No. 3 — Anode

RCA
Solid State
Division

Thyristors
S6200 S6210 S6220 Series



PRESS-FIT
S6200
Series

CATHODE
GATE
H-1612
ANODE

STUD
S6210
Series

CATHODE
GATE
ANODE
H-1658

ISOLATED-STUD
S6220
Series

20-Ampere Silicon Controlled Rectifiers

Press-Fit, Stud, and Isolated-Stud Packages

Package \ Voltage	100 V Types	200 V Types	400 V Types	600 V Types
Press-fit	S6200A (40749)	S6200B (40750)	S6200D (40751)	S6200M (40752)
Stud	S6210A (40753)	S6210B (40754)	S6210D (40755)	S6210M (40756)
Isolated-Stud	S6220A (40757)	S6220B (40758)	S6220D (40759)	S6220M (40760)

Numbers in parentheses are former RCA type numbers.

These RCA types are all-diffused, silicon controlled rectifiers (reverse-blocking triode thyristors) designed for power switching and voltage regulator applications and for heating, lighting and motor speed-control circuits.

These SCRs have an RMS on-state current rating ($I_{T\,[RMS]}$) of 20 A and have voltage ratings (V_{DROM}) of 100, 200, 400, and 600 volts.

Features:

- Low switching losses
- High di/dt and dv/dt capabilities
- Shorted-emitter gate-cathode construction
- Forward and reverse gate dissipation ratings
- All-diffused construction—assures exceptional uniformity and stability of characteristics
- Symmetrical gate-cathode construction—provides uniform current density, rapid electrical conduction, and efficient heat dissipation
- Low leakage currents, both forwa and reverse
- Low forward voltage drop at high current levels
- Low thermal resistance

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		S6200A S6210A S6220A	S6200B S6210B S6220B	S6200D S6210D S6220D	S6200M S6210M S6220M	
NON-REPETITIVE PEAK REVERSE VOLTAGE						
Gate Open	V_{RSOM}	150	250	500	700	V
NON-REPETITIVE PEAK FORWARD VOLTAGE						
Gate Open	V_{DSOM}	150	250	500	700	V
REPETITIVE PEAK REVERSE VOLTAGE						
Gate Open	V_{RROM}	100	200	400	600	V
REPETITIVE PEAK OFF-STATE VOLTAGE						
Gate Open	V_{DROM}	100	200	400	600	V
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:						
For one cycle of applied principal voltage $T_C = 75^oC$	I_{TSM}					
50-Hz, (sinusoidal)		170				A
60-Hz, (sinusoidal)		200				A
For more than one full cycle of applied principal voltage		See Fig. 10				
ON-STATE CURRENT:						
For case temperature (T_C) = 75° C, conduction angle of 180°						
Average DC value	$I_{T(AV)}$	12.5				A
RMS value	$I_{T(RMS)}$	20				A
RATE-OF-CHANGE OF ON-STATE CURRENT:						
$V_{DM} = V_{(BO)O}$, I_{GT} = 200 mA, t_r = 0.5 μs (See Fig. 2.)	di/dt	200				A/μs
FUSING CURRENT (for SCR protection):						
T_J = −65 to 100°C, t = 1 to 8.3 ms	I^2t	170				A^2s
GATE POWER DISSIPATION:						
PEAK FORWARD (for 10 μs max.)	P_{GM}	40				W
AVERAGE (averaging time = 10 ms, max.)	$P_{G(AV)}$	0.5				W
PEAK REVERSE	P_{RGM}	See Fig. 5				

MAXIMUM RATINGS, *Absolute-Maximum Values:* *(Cont'd)*	S6200A S6210A S6220A	S6200B S6210B S6220B	S6200D S6210D S6220D	S6200M S6210M S6220M	
TEMPERATURE RANGE:					
Storage	−65 to 150				°C
Operating (Case)	−65 to 100				°C
Soldering (10 s max. for terminals)	225				°C

LECTRICAL CHARACTERISTICS

t Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	SYMBOL	LIMITS – ALL TYPES			UNITS
		Min.	Typ.	Max.	
Instantaneous Forward Breakover Voltage: (Gate open, T_C = 100 °C)	$v_{(BO)O}$				V
S6200A, S6210A, S6220A		100	–	–	
S6200B, S6210B, S6220B		200	–	–	
S6200D, S6210D, S6220D		400	–	–	
S6200M, S6210M, S6220M		600	–	–	
Peak Off-State Current: (Gate open, T_C = 100 °C) Forward, $V_{DO} = V_{DROM}$	I_{DOM}	–	0.2	3	mA
Reverse, $V_{RO} = V_{RROM}$	I_{RROM}	–	0.1	2	
Instantaneous On-State Voltage: For i_T = 100 A, T_C = 25 °C	v_T	–	1.9	2.4	V
DC Gate Trigger Current: V_D = 12 V (DC), R_L = 30Ω, T_C = 25 °C At other case temperatures	I_{GT}	–	8 See Fig. 11	15	mA
DC Gate Trigger Voltage: V_D = 12 V (DC), R_L = 30Ω, T_C = 25 °C At other case temperatures	V_{GT}		1.1 See Fig. 12	2	V
Instantaneous Holding Current: Gate open, T_C = 25 °C At other case temperatures	i_{HO}		9 See Fig. 15	20	mA
Critical Rate-of-Rise of Off-State Voltage: ($V_{DO} = v_{(BO)O}$ Min. value, Exponential rise, T_C = 100°C, See Fig 5)	dv/dt				V/μs
S6200A, S6200D, S6210A, S6210D, S6220A, S6220D		10	100	–	
S6200B, S6210B, S6220B		10	150	–	
S6200M, S6210M, S6220M		10	75	–	
Gate Controlled Turn-On Time: $V_D = v_{(BO)O}$ Min. value, i_T = 30 A, I_{GT} = 200 mA, 0.1 μs rise time, T_C = 25°C See Fig. 9	t_{gt}	–	2	–	μs
Circuit Commutated Turn-Off Time: $V_D = V_{F(BO)O}$ Min. value, i_T = 18 A, Pulse Duration = 50 μs, **dv/dt = 20 V/μs, di/dt = −30 A/μs, T_C = 75°C** See Fig. 4	t_q	–	20	40	μs
Thermal Resistance: Junction-to-Case **(press-fit, stud packages)**	$R_{\theta JC}$	–	–	1.2	°C/W
Junction-to-Isolated Stud **(Isolated-stud package)**	$R_{\theta JIS}$	–	–	1.4	

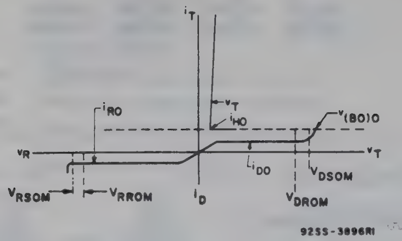

i_T
i_{RO}
v_T
i_{HO}
$v_{(BO)O}$
v_R
v_T
i_{DO}
V_{DSOM}
V_{RSOM}
V_{RROM}
i_D
V_{DROM}
92SS-3896RI

Fig. 1—Principal voltage-current characteristic.

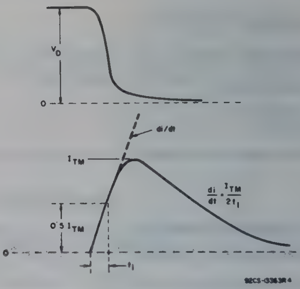

v_D
0
di/dt
I_{TM}
$\frac{di}{dt} = \frac{I_{TM}}{2t_1}$
0.5 I_{TM}
0
t_1
92CS-13363R4

Fig. 2—Rate of change of on-state current with time (defining di/dt)

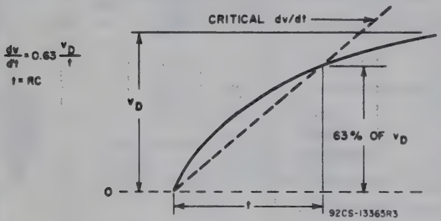

$\frac{dv}{dt} = 0.63 \frac{v_D}{t}$
t = RC
CRITICAL dv/dt
v_D
63% OF v_D
0
t
92CS-13365R3

Fig. 3—Rate of rise of off-state voltage with time (defining dv/dt).

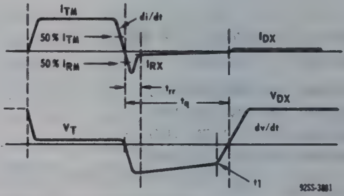

I_{TM}
di/dt
50% I_{TM}
I_{DX}
50% I_{RM}
I_{RX}
t_{rr}
t_q
V_{DX}
V_T
dv/dt
t1
92SS-3881

Fig. 4—Relationship between on-state current, reverse current, o state voltage, and off-state voltage showing reference point for definition of turn-off time (t_g).

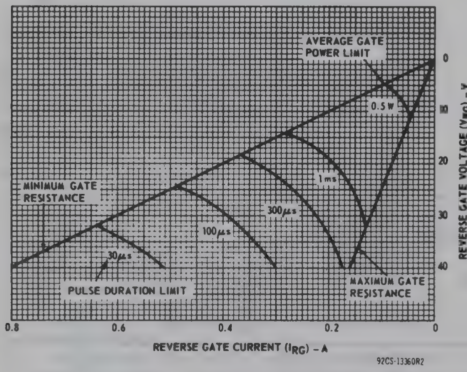


Fig. 5—Reverse gate voltage vs. reverse gate current.

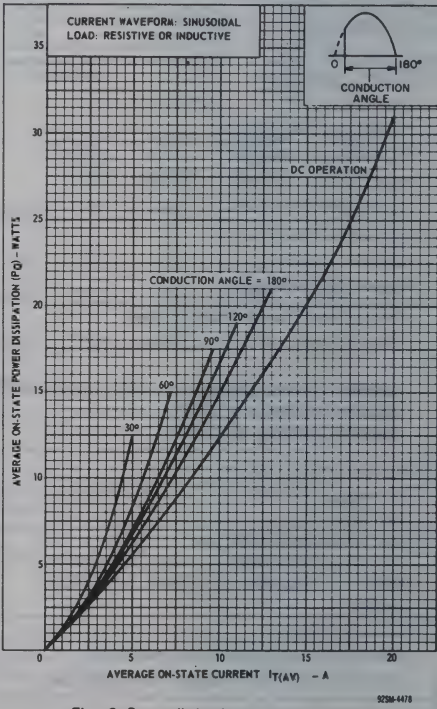


Fig. 6—Power dissipation vs. on-state current.

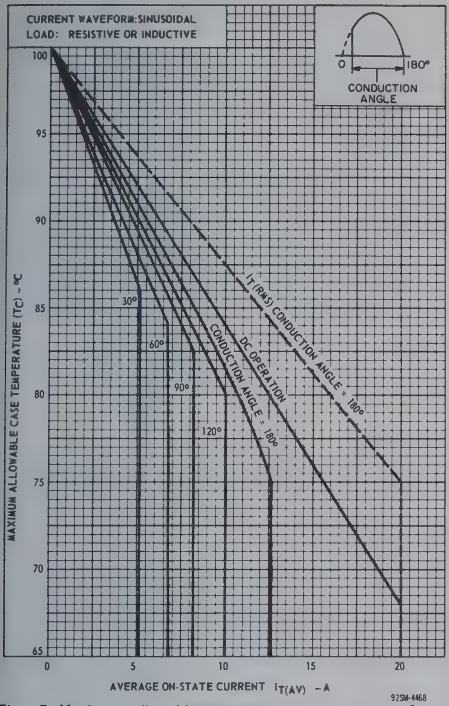


Fig. 7—Maximum allowable case temperature vs. average forward current for stud and press-fit.

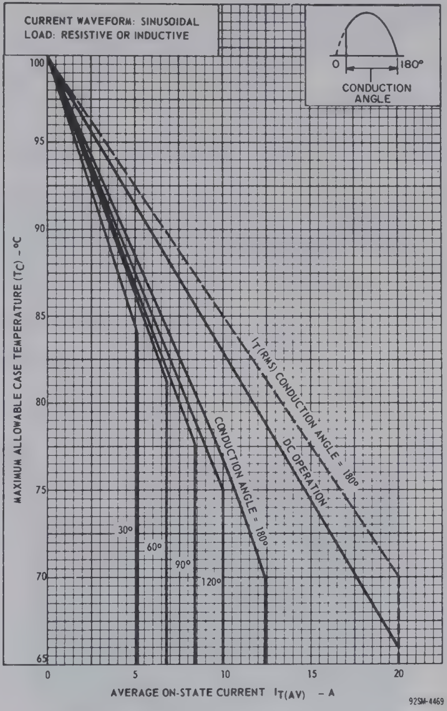


Fig. 8—Maximum allowable case temperature vs. average forward current for isolated stud.

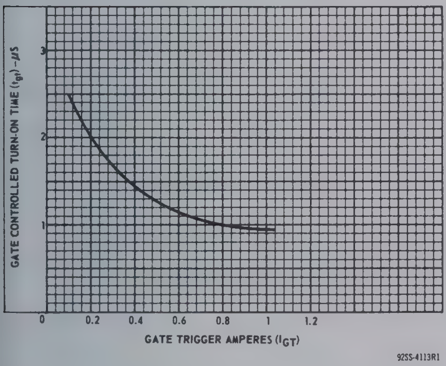


Fig. 9—Gate controlled turn-on time (t_{gt}) vs. gate-trigger current.

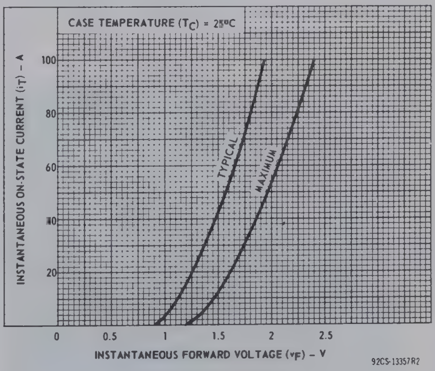


Fig. 10—Instantaneous on-state current vs. on-state voltage.

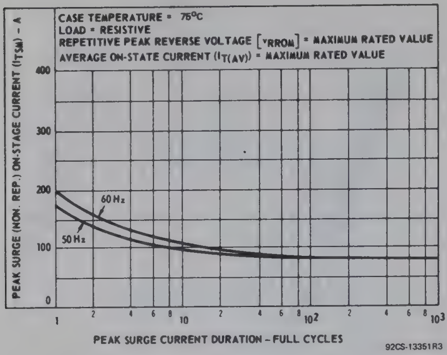


Fig. 11—Peak surge on-state current vs. surge current duration.

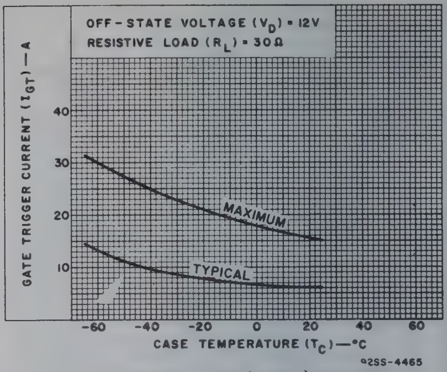


Fig. 12—DC gate-trigger current (forward) vs. case temperature.

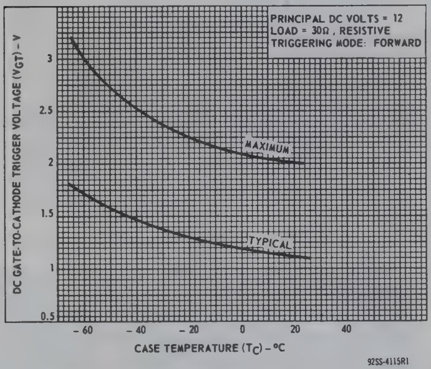


Fig. 13—DC gate-trigger voltage vs. case temperature.

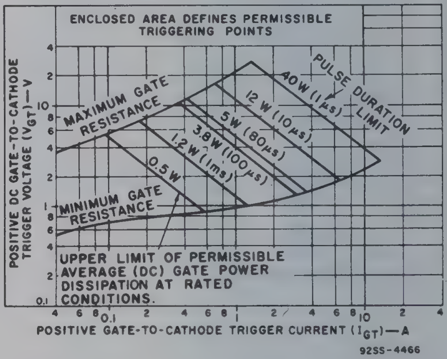


Fig. 14—Typical forward-biased gate trigger characteristics.

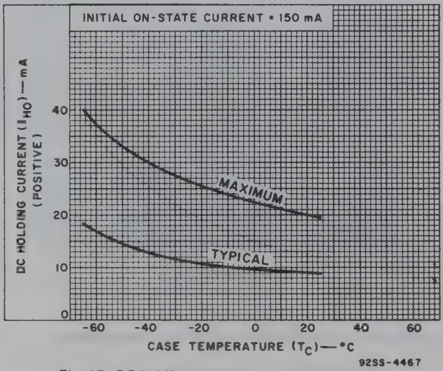


Fig. 15—DC holding current vs. case temperature.

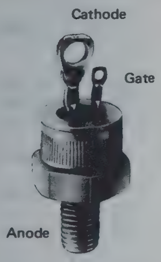
TERMINAL CONNECTIONS

No. 1 — Gate
No. 2 — Cathode
No. 3 — Anode

RCA
Solid State Division

Thyristors

S6431M



JEDEC TO-48 H-1601

Silicon Controlled Rectifier for High-Current Pulse Applications

Features:

- Up to 900 Amperes Peak Forward Current Pulses
- 30 Watts Maximum Average Dissipation
- Forward Current of 35 Amperes (rms value)
- Shorted-Emitter Design
- All-Diffused Construction — Assures Exceptional Uniformity and Stability
- Direct Soldered Internal Construction — Assures Exceptional Resistance to Fatigue

The S6431M (formerly RCA type 40216) is an all-diffused, three-junction silicon controlled rectifier (SCR) designed especially for use in radar pulse modulators, inverters, switching regulators, and other applications requiring a large ratio of peak to average current. It is especially constructed for rapid spread of forward current over the full junction area to achieve a high rate of change of forward current (di/dt) capability and low switching dissipation.

Absolute-Maximum Ratings

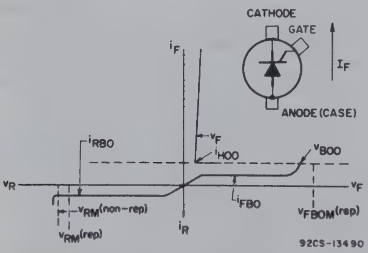
RATINGS	CONTROLLED-RECTIFIER TYPE	UNITS
	S6431M	
Transient Peak Reverse Voltage (Non-Repetitive), v_{RM} (non-rep)	720	volts
Peak Reverse Voltage (Repetitive), v_{RM} (rep)	600	volts
Peak Forward Blocking Voltage (Repetitive), v_{FBOM} (rep)	600	volts
Forward Current:		
For case temperature of +65°C, RMS value, I_{FRMS}	35	amperes
Peak Pulse Current (See *Fig.7*)	900	amperes
Rate of Change of Forward Current, di/dt	See *Fig.7*	
Dynamic Dissipation:		
For case temperature of +65° C	30	watts
For other case temperatures	See *Fig.4*	
Gate Power*:		
Peak, Forward or Reverse, for 10 µs duration, P_{GM} (See *Figs.10 and 11*)	40	watts
Average, P_{GAV}	0.5	watt
Temperature:		
Storage, T_{stg}	–65 to +150	°C
Operating (Case), T_C	–65 to +125	°C

*Any values of peak gate current or peak gate voltage to give the maximum gate power is permissible.

Characteristics at Maximum Ratings (unless otherwise specified), and at Indicated Case Temperature (T_C)

CHARACTERISTICS	CONTROLLED-RECTIFIER TYPE			UNITS
	S6431M			
	Min.	*Typ.*	*Max.*	
Forward Breakover Voltage, v_{BOO} At T_C = +125° C	600	–	–	volts
Instantaneous Blocking Current, At T_C = +125° C				
Forward, i_{FBO}	–	–	10	mA
Reverse, i_{RBO}	–	–	10	mA
Forward Voltage Drop, v_F		See *Fig.5*		
DC Gate-Trigger Current, I_{GT} : At T_C = +25° C (See *Fig.10*)	1	25	80	mA(dc)
DC Gate-Trigger Voltage, V_{GT} : At T_C = +25° C (See *Fig.10*)	–	1.1	2	volts(dc)
Holding Current, i_{HOO} : At T_C = +25° C	0.5	20	70	mA
Critical Rate of Applied Forward Voltage, Critical dv/dt V_{FB} = v_{BOO} (min. value), exponential rise, and T_C = +125° C (See waveshape of *Fig.1*)	20	50	–	volts/ microsecond
Turn-On Time, t_{on}, (Delay Time + Rise Time) V_{FB} = v_{BOO} (min. value), i_F = 30 A, I_{GT} = 200 mA, 0.1 µs min. rise time, and T_C = +25° C (See waveshapes of *Fig.2*)	–	1.25	–	microsecond
Turn-Off Time, t_{off}, (Reverse Recovery Time + Gate Recovery Time) i_F = 18 A, 50 µs pulse width, dv_{FB}/dt = 20 V/µs, di_r/dt = 30 A/µs, I_{GT} = 200 mA, and T_C = +80° C (See waveshapes of *Fig.3*)	15	20	40	microseconds
Thermal Resistance, Junction-to-Case	–	–	2	°C/W

TYPICAL E-I CHARACTERISTIC OF SILICON CONTROLLED-RECTIFIER


CATHODE
GATE
I_F
ANODE (CASE)
i_F
v_F
i_{RBO}
i_{HOO}
v_{BOO}
v_R
v_F
i_{FBO}
v_{RM}(non-rep)
v_{RM}(rep)
i_R
v_{FBOM}(rep)
92CS-13490

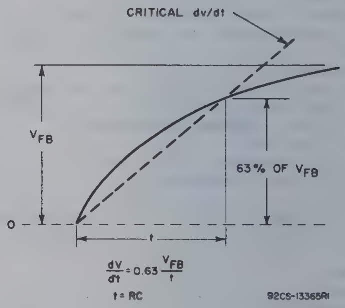

CRITICAL dv/dt
V_{FB}
63% OF V_{FB}
0
t
$\frac{dV}{dt} = 0.63 \frac{V_{FB}}{t}$
t = RC
92CS-13365R1

Fig. 1—Waveshape of critical dv/dt rating test.

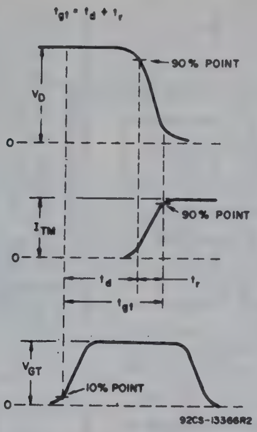

$t_{gt} = t_d + t_r$
90% POINT
V_D
0
I_{TM}
90% POINT
0
t_d
t_r
t_{gt}
V_{GT}
10% POINT
0
92CS-13366R2

Fig. 2–Waveshape of t_{on} rating test.

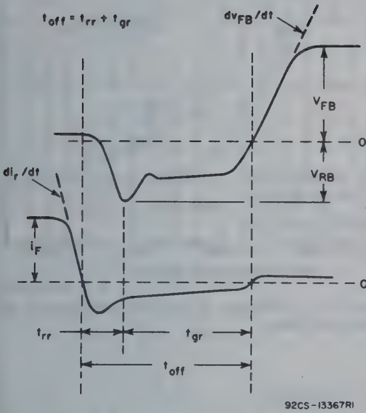

$t_{off} = t_{rr} + t_{gr}$
dv_{FB}/dt
V_{FB}
0
V_{RB}
di_r/dt
i_F
0
t_{rr}
t_{gr}
t_{off}
92CS-13367R1

Fig. 3–Waveshape of t_{off} rating test.

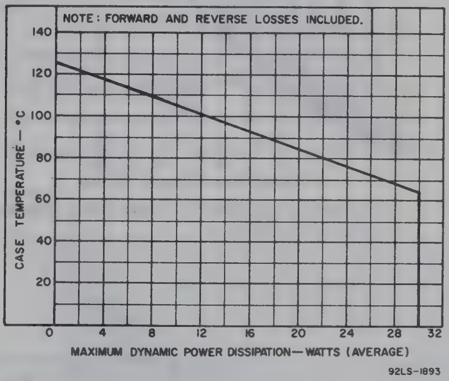


Fig. 4–Maximum average total power dissipation as a function of case temperature.

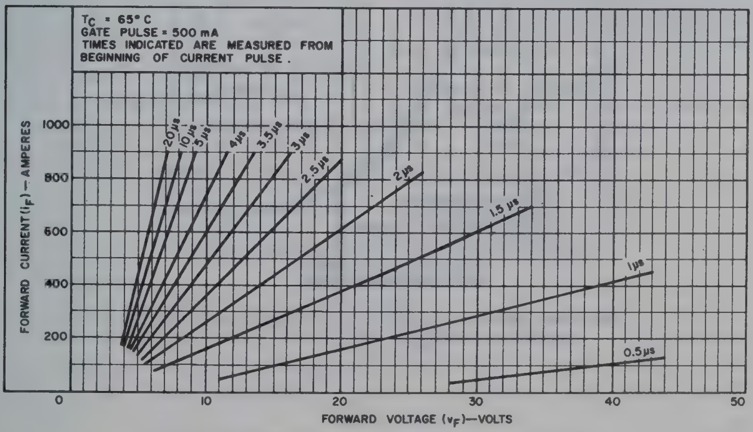
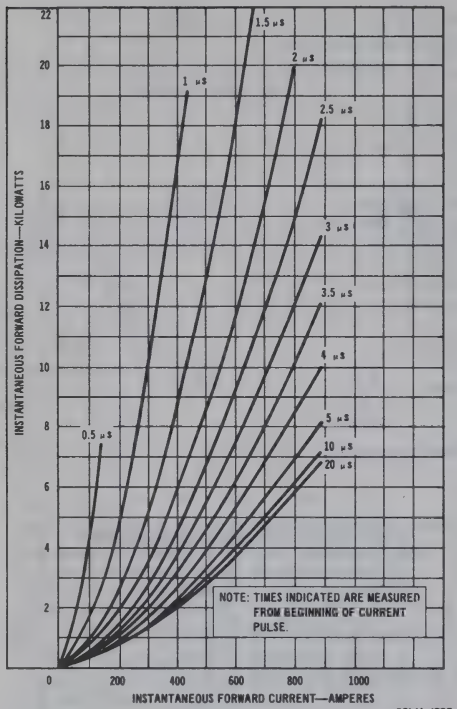
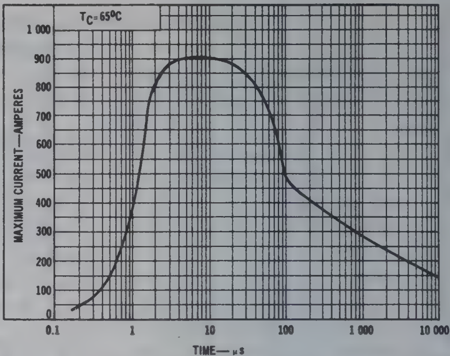


Fig. 5–Forward voltage-current characteristics as a function of time.



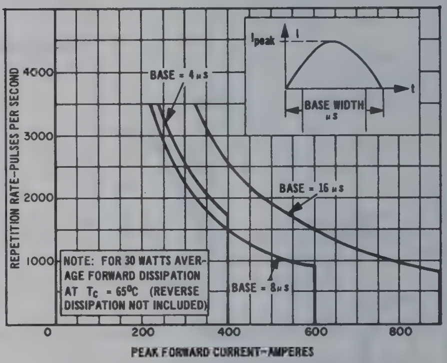
92LM-1896

Fig. 6—Instantaneous forward dissipation-forward current characteristics as a function of time.



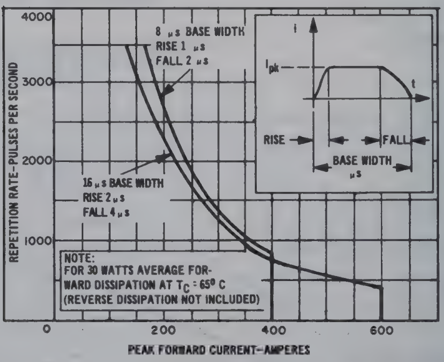
92LS-1896

Fig. 7—Maximum current as a function of time.



92LS—1898

Fig. 8—Peak current as a function of maximum repetition rate for sine-wave pulse shapes.



92LS—1897

Fig. 9—Peak current as a function of maximum repetition rate for square-wave pulse shapes.

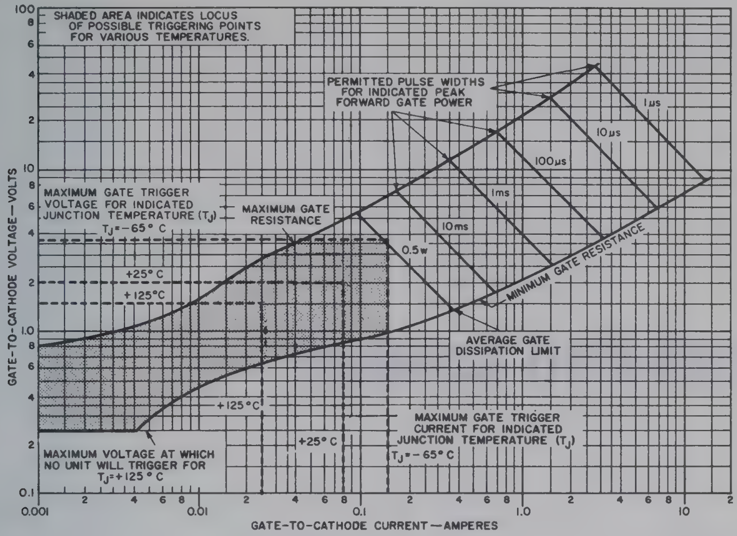


Fig. 10—Forward gate characteristics.

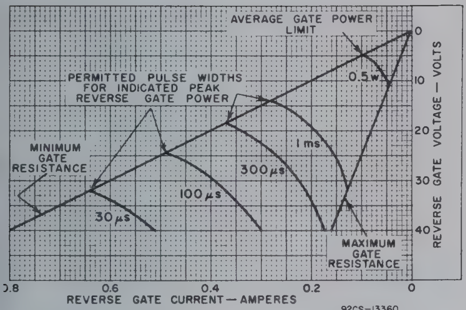


Fig. 11—Reverse gate characteristics.

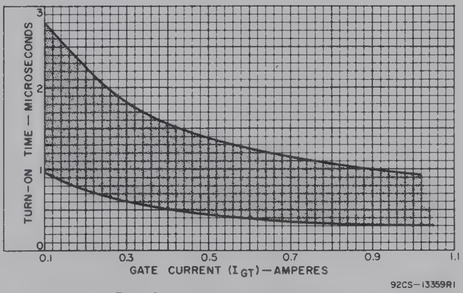


Fig. 12—Turn-on time characteristics.

TERMINAL CONNECTIONS

No. 1 — Gate
No. 2 — Cathode
No. 3 — Anode

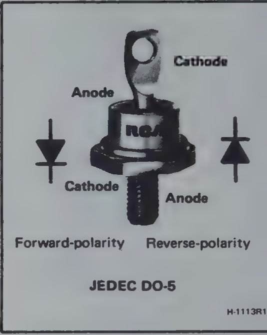
Technical Data-Rectifiers

RCA
Solid State Division

Rectifiers

1N248C 1N249C 1N250C 1N1195A 1N1196A 1N1197A 1N1198A

Stud-Mounted Types for Industrial and Military Power Supplies



JEDEC DO-5

Applications:

In power supplies for mobile equipment, dc-to-dc converters, battery chargers, dynamic braking systems, aircraft and missile power supplies, high-power transmitter and rf-generator power supplies, machine-tool controls, dc-motor power supplies, and in other heavy-duty industrial and military equipment.

HALF-WAVE RECTIFIER SERVICE

Maximum Ratings:

Absolute-Maximum Values for Supply Frequency of 60 cps, Single-Phase Operation, and with Resistive or Inductive Load

	1N248-C	1N249-C	1N250-C	1N1195-A	1N1196-A	1N1197-A	1N1198-A
PEAK INVERSE VOLTS	55	110	220	300	400	500	600
RMS SUPPLY VOLTS	39	77	154	212	284	355	424
DC BLOCKING VOLTS	50	100	200	300	400	500	600
FORWARD AMPERES:							
Average DC:							
At 150° C case temperature. .	20	20	20	20	20	20	20
At other temperatures	See Rating Chart I						
PEAK RECURRENT AMPERES . . .	90	90	90	90	90	90	90
PEAK SURGE AMPERES:♦							
(One-half cycle, sine wave) . . .	350	350	350	350	350	350	350
(For more than one cycle). . .	See Rating Chart IV						
CASE TEMPERATURE:							
Operating and Storage .	-65 to +175° C						
STUD TORQUE:							
Recommended . .	30 in-lb						
Maximum (DO NOT EXCEED). .	50 in-lb						

♦ Superimposed on device operating within the maximum specified voltage, current, and temperature ratings and may be repeated after sufficient time has elapsed for the device to return to the presurge thermal equilibrium conditions.

- available in reverse-polarity versions: 1N248-RC, 1N249-RC, 1N250-RC, 1N1195-RA, 1N1196-RA, 1N1197-RA, 1N1198-RA
- designed to meet stringent military mechani-cal and environmental specifications
- diffused-junction process — exceptional uni-formity of characteristics
- hermetic seals
- welded constructio
- low thermal resistance
- low leakage curren
- low forward voltage drop
- JEDEC DO-5 outlin
- high output current: up to

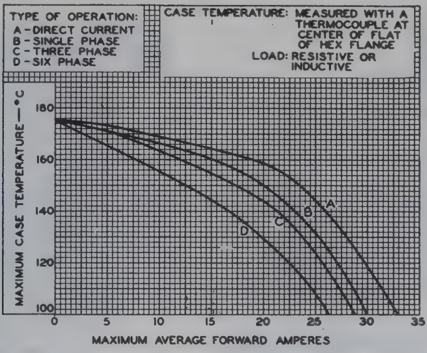
  84 amperes — 6 rectifiers in 3-phase, full-wave bridge circuit

  60 amperes — 4 rectifiers in single-phase full-wave bridge circuit

Characteristics at 150° C Case Temperatur

Max. Forward Voltage Drop● (Volts) . . .	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Max. Reverse Current● (Ma.)	3.8	3.6	3.4	3.2	2.5	2.2	1.5

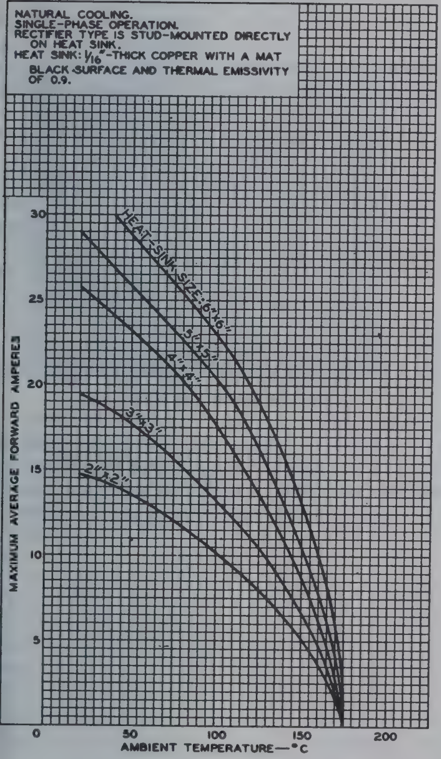
● At maximum peak inverse voltage, average forward amperes = 20, and averaged over one complete cycle.


TYPE OF OPERATION:
A - DIRECT CURRENT
B - SINGLE PHASE
C - THREE PHASE
D - SIX PHASE

CASE TEMPERATURE: MEASURED WITH A THERMOCOUPLE AT CENTER OF FLAT OF HEX FLANGE
LOAD: RESISTIVE OR INDUCTIVE

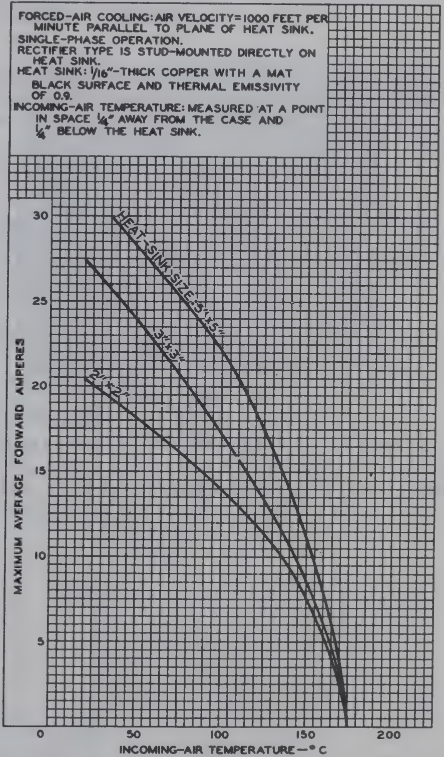
92CS-10746

Fig. 1 - Rating Chart 1 for Types 1N248-C, 1N249-C, 1N250-C, 1N1195-A, 1N1196-A, 1N1197-A, 1N1198-A, and corresponding reverse-polarity versions.


NATURAL COOLING.
SINGLE-PHASE OPERATION.
RECTIFIER TYPE IS STUD-MOUNTED DIRECTLY ON HEAT SINK.
HEAT SINK: 1/16"-THICK COPPER WITH A MAT BLACK SURFACE AND THERMAL EMISSIVITY OF 0.9.

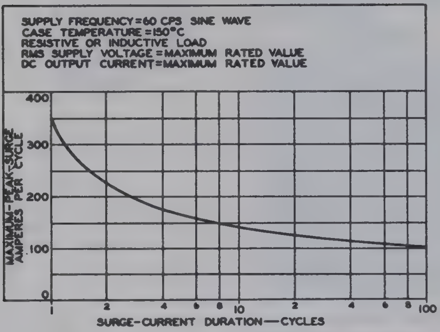
92CM-10741

ig.2 - Rating Chart II for Types 1N248-C, 1N249-C, 1N250-C, 1N1195-A, 1N1196-A, 1N1197-A, 1N1198-A, and corresponding reverse-polarity versions.


FORCED-AIR COOLING: AIR VELOCITY=1000 FEET PER MINUTE PARALLEL TO PLANE OF HEAT SINK.
SINGLE-PHASE OPERATION.
RECTIFIER TYPE IS STUD-MOUNTED DIRECTLY ON HEAT SINK.
HEAT SINK: 1/16"-THICK COPPER WITH A MAT BLACK SURFACE AND THERMAL EMISSIVITY OF 0.9.
INCOMING-AIR TEMPERATURE: MEASURED AT A POINT IN SPACE 1/4" AWAY FROM THE CASE AND 1/4" BELOW THE HEAT SINK.

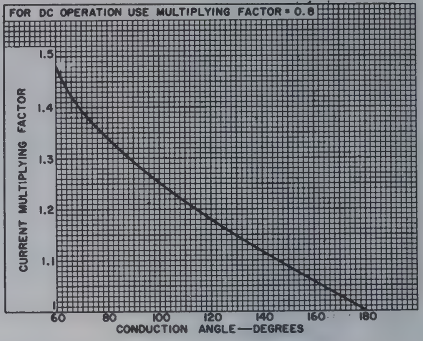
92CM-10745

Fig. 3 - Rating Chart III for Types 1N248-C, 1N249-C, 1N250-C, 1N1195-A, 1N1196-A, 1N1197-A, 1N1198-A, and corresponding reverse-polarity versions.



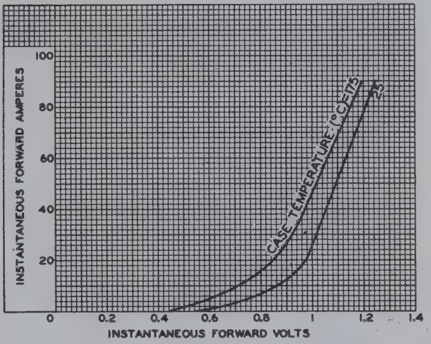
92CS-10909

Fig.4 - Rating Chart IV for Types 1N248-C, 1N249-C, 1N250-C, 1N1195-A, 1N1196-A, 1N1197-A, 1N1198-A, and corresponding reverse-polarity versions.



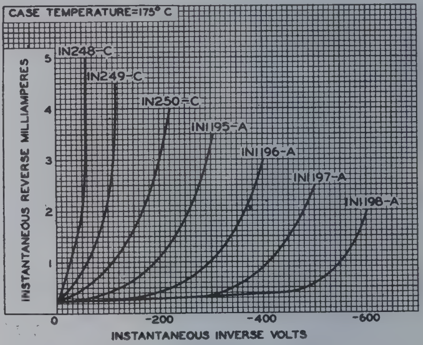
92CS-10910

Fig.5 - Chart V for Types 1N248-C, 1N249-C, 1N250-C, 1N1195-A, 1N1196-A, 1N1197-A, 1N1198-A, and corresponding reverse-polarity versions.



92CS-10768

Fig.6 - Typical Forward Characteristics for Types 1N248-C, 1N249-C, 1N250-C, 1N1195-A, 1N1196-A, 1N1197-A, 1N1198-A, and corresponding reverse-polarity versions.



92CS-10767

Fig.7 - Typical Reverse Characteristic for Types 1N248-C, 1N249-C, 1N250-C 1N1195-A, 1N1196-A, 1N1197-A, 1N1198-A, and corresponding reverse-polarity versions.

Solid State
Division

Rectifiers

1N440B 1N443B
1N441B 1N444B
1N442B 1N445B

RCA-1N440B, 1N441B, 1N442B, 1N443B, 1N444B, d 1N445B are hermetically sealed silicon rectifiers of e diffused-junction type, designed for use in power pplies of magnetic amplifiers, radio receivers, dc ocking circuits, power supplies, and other military d industrial applications.

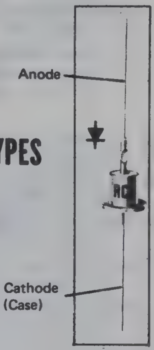
These devices have dc forward-current ratings 0.75 ampere at an ambient temperature of 25°C, d peak reverse voltage ratings of 100, 200, 300, 400, 0 and 600 volts, respectively.

The 1N440B through 1N445B feature (1) sturdy d compact mount structure, (2) axial leads for flexi- ity of circuit connections, (3) welded hermetic seals— ery unit is pressure-tested to assure protection ainst moisture and contamination, (4) superior junc- n formation made possible by a diffusion process th very precise controls. In addition, these devices e designed to meet the following stringent environ- ntal, mechanical and life requirements of prime portance in military applications: (a) special temper- ure-cycling tests to assure stable performance over e entire operating temperature range, (b) special ating to provide protection against the effects of se- e environmental conditions,

DIFFUSED-JUNCTION SILICON RECTIFIERS

FLANGED-CASE AXIAL-LEAD TYPES

For Power-Supply Applications In Industrial and Military Electronic Equipment



H-967
JEDEC DO-1

FEATURES:

- stringent environmental and mechanical tests to insure dependable performance in industrial and military applications
- hermetically sealed JEDEC DO-1 package
- wide operating-temperature range:

Types	Range
1N440B 1N441B 1N442B 1N443B	-65 to +165°C
1N444B 1N445B	-65 to +150°C

RECTIFIER SERVICE

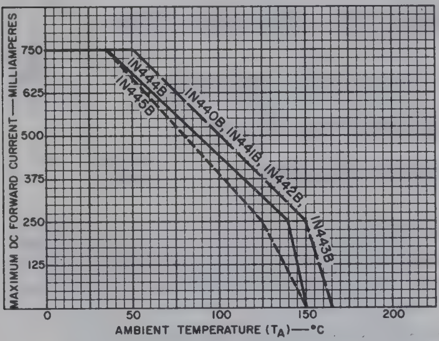
bsolute-Maximum Ratings, for a Supply Frequency of 60 Hz:

	1N440B	1N441B	1N442B	1N443B	1N444B	1N445B	UNITS
EAK REVERSE VOLTAGE	100	200	300	400	500	600	V
MS SUPPLY VOLTAGE							
For resistive or inductive loads	70	140	210	280	350	420	V
C REVERSE (BLOCKING) VOLTAGE .	100	200	300	400	500	600	V
ORWARD CURRENT:[a]							
DC:							
at $T_A = 50^oC$	750	750	750	750	650	650	mA
at $T_A = 100^oC$	500	500	500	500	425	400	mA
at $T_A = 150^oC$	250	250	250	250	0	0	mA
Peak, Repetitive	3.5	3.5	3.5	3.5	3.5	3.5	A
Surge, One-Cycle	15	15	15	15	15	15	A
EMPERATURE RANGE (Ambient):							
Operating.	165	165	165	165	150	150	°C
Storage	← -65 to +175 →						°C

For maximum dc forward current values at ambient temperatures other than those specified, See Rating Chart Fig. 1.

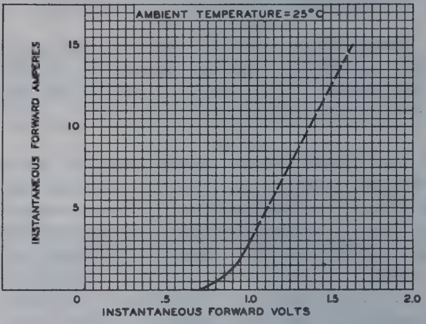
Characteristics, at Ambient Temperature (T_A) = 25°C

CHARACTERISTICS	1N440B	1N441B	1N442B	1N443B	1N444B	1N445B	UNITS
Maximum Forward Voltage Drop (DC) at full load current.	1.5	1.5	1.5	1.5	1.5	1.5	V
Maximum Reverse Current (DC) at maximum peak reverse voltage	0.3	0.75	1	1.5	1.75	2	μA
Maximum Reverse Current (averaged over 1 complete cycle of supply voltage): at maximum rated PRV, T_A = 150°C	100	100	200	200	200	200	μA



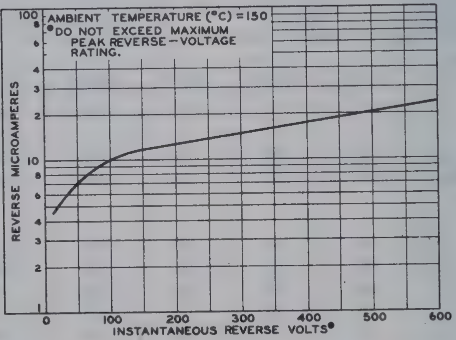
92CS-14118

Fig.1 - Rating Chart for RCA-1N440B through 1N445B.



92CS-10063

Fig.2 - Typical Forward Voltage and Current Characteristic for RCA-1N440B through 1N445B.



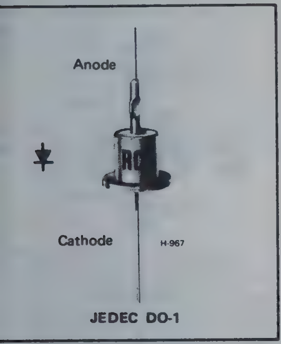
92CS-10064R1

Fig.3 - Typical Dynamic Reverse Characteristic for RCA-1N440B through 1N445B.

RCA
Solid State Division

Rectifiers

1N536 1N538 1N540
1N537 1N539 1N547 1N1095



JEDEC DO-1

Diffused-Junction Silicon Rectifiers

Flanged-Case, Axial-Lead Types For Power-Supply Applications

Features:

- **Wide operating-temperature range : -65 to +65°C.**
- **Stringent environmental and mechanical tests to insure dependable performance in industrial and military applications.**
- **Peak reverse voltages from 50 to 600 V.**
- **Max. dc forward current = 250 mA at T_A = 150°C.**
- **Hermetically sealed JEDEC DO-1 package.**

CA-1N536, 1N537, 1N538, 1N539, 1N540, 1N547, and N1095 are hermetically sealed silicon rectifiers of the iffused-junction type. They are specifically designed for se in power supplies of industrial and military equipment apable of operating at dc forward currents up to 750 illiamperes and temperatures ranging from -65° to +165°C.

hese silicon rectifiers have peak reverse voltage ratings from 0 to 600 volts, and a maximum reverse current of 5 microamperes at rated peak reverse voltage and ambient temperature of 25°C.

These silicon rectifiers are designed to meet such stringent environmental, mechanical, and life requirements of prime importance in military applications as: (1) sturdy and compact mount structure, (2) axial leads for flexibility of circuit connections, (3) welded hermetic seals, and (4) special temperature cycling tests to assure stable performance over the entire operating temperature range.

RECTIFIER SERVICE, ABSOLUTE-MAXIMUM RATINGS, *for a Supply Frequency of 60 Hz:*

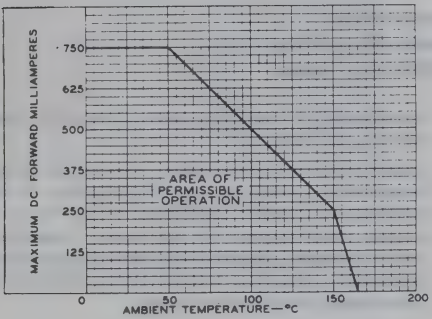
	1N536	1N537	1N538	1N539	1N540	1N1095	1N547	
EAK REVERSE VOLTAGE	50	100	200	300	400	500	600	V
MS SUPPLY VOLTAGE								
For resistive or inductive loads	35	70	140	210	280	350	420	V
C REVERSE – (BLOCKING) VOLTAGE	50	100	200	300	400	500	400	V
ORWARD CURRENT*:								
C, for resistive or inductive loads:								
T_A = 50°C	750	750	750	750	750	750	750	mA
URGE, one cycle	15	15	15	15	15	15	15	A
PERATING FREQUENCY	100	100	100	100	100	100	100	kHz
EMPERATURE RANGE (Ambient):								
Operating	← -65 to +165 →							°C
Storage	← -65 to +175 →							°C

---

*For maximum dc forward current values at ambient temperatures other than those specified, see Rating Chart, Fig. 1.

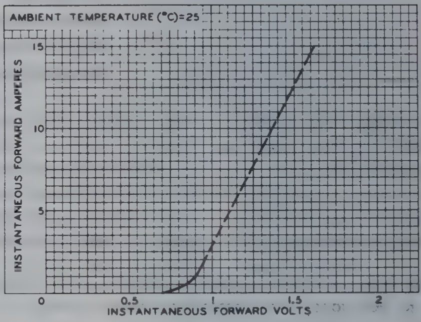
CHARACTERISTICS, at Ambient Temperature (T_A) = 25°C:

	1N536	1N537	1N538	1N539	1N540	1N547	1N1095
Maximum Forward Voltage Drop (DC) at a load current of 500 mA	1.1	1.1	1.1	1.1	1.1	1.2	1.2
Maximum Reverse Current (DC) at maximum peak reverse voltage	5	5	5	5	5	5	5
Maximum Reverse Current (Averaged over 1 complete cycle of supply voltage): at maximum rated PRV, T_A = 150°C	0.4	0.4	0.3	0.3	0.3	0.35	0.3



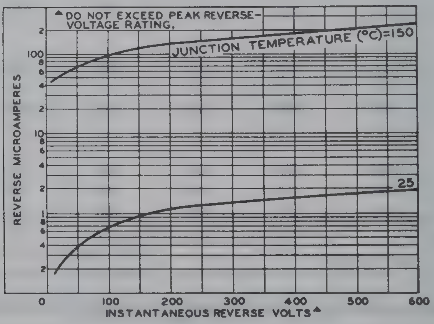
92CS-10082

Fig.1— Rating chart.



92CS-10083

Fig.2— Typical forward voltage and current characteristic.



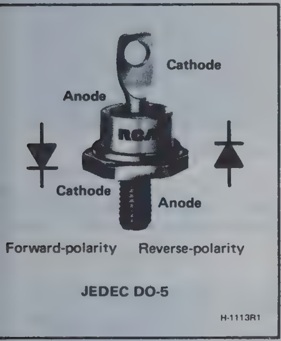
92CS-10137R1

Fig.3— Typical dynamic reverse characteristics.

RCA
Solid State
Division

Rectifiers

1N1183A 1N1184A
1N1186A-1N1190A



40-Ampere Silicon Rectifiers

Stud-Mounted Types for Industrial and Military Power Supplies

Features:

- **Low thermal resistance**
- **Low forward voltage drop**
- **High output current:**
  up to 160 amperes — 6 rectifiers in 3-phase, full-wave bridge circuit
  up to 120 amperes — 4 rectifiers in single-phase, full-wave bridge circuit
- **Available in reverse-polarity versions:**
  1N1183RA, 1N1184RA, 1N1186RA, 1N1187RA, 1N1188RA, 1N1189RA, 1N1190RA
- **Extra-high-strength zirconium-alloy mounting stud — withstands installation torque of up to 50 inch-pounds**
- **Designed to meet stringent military mechanical and environmental specifications.**
- **Welded construction**
- **Low leakage current**
- **JEDEC DO-5 Outline**

RCA-1N1183A, 1N1184A, 1N1186A, 1N1187A, 1N1188A, N1189A, and 1N1190A are 40-ampere, diffused-junction ilicon rectifiers suitable for use in generator-type power upplies for mobile electrical and electronic equipment, in lc-to-dc converters and battery chargers, and in power upplies for aircraft, marine, and missile equipment, transnitters, and rf generators. They are also extremely useful in ower supplies for dc motors, in welding and electroplating quipment, in dc-blocking applications, in magnetic ampliiers, and in a wide variety of other applications in eavy-duty industrial and military equipment.

- **Diffused-junction process — exceptional uniformity and stability of characteristics**
- **Hermetic seals**

These rectifiers are conservatively rated to permit continuous operation at maximum ratings in applications requiring high reliability under severe operating conditions. In addition, they utilize a special zirconium-alloy mounting stud which can withstand installation torques of up to 50 inch-pounds — a feature of significant value in applications involving mechanical shock and vibration.

IALF-WAVE RECTIFIER SERVICE, ABSOLUTE-MAXIMUM RATINGS, ***for Supply Frequency of 60 cps, Single-phase Operation, nd with Resistive or Inductive Load***

	1N1183A	1N1184A	1N1186A	1N1187A	1N1188A	1N1189A	1N1190A
'EAK REVERSE VOLTS	50	100	200	300	400	500	600
RMS SUPPLY VOLTS	35	70	140	212	284	355	424
)C BLOCKING VOLTS	50	100	200	300	400	500	600
AVERAGE FORWARD AMPERES:							
At 150°C case temperature	40						
At other case temperatures	See Fig. 1						
'EAK SURGE AMPERES:[a]							
One-half cycle, sine wave	800						
For more than one cycle	See Fig. 5						
'EAK RECURRENT AMPERES	195						
CASE TEMPERATURE RANGE:							
Operating and storage	-65 to +200°C						
haracteristics:							
lax. Forward Voltage Drop (Volts)[b]	0.65						
lax. Reverse Current (mA):							
Dynamic[b]	2.5	2.5	2.5	2.5	2.2	2	1.8
Static[c]	0.015						
lax. Thermal Resistance, Junction-to-Case	1° C/W						
TUD TORQUE:							
Recommended	30 in-lb						
Maximum (DO NOT EXCEED)	50 in-lb						

Superimposed on device operating within the maximum specified voltage, current, and temperature ratings and may be repeated after sufficient time has elapsed for the device to return to the presurge thermal-equilibrium conditions.

[b] Average value for one complete cycle, at maximum peak reverse voltage, maximum average forward amperes = 40, and case temperature (°C) = 150.

[c] DC value, at maximum peak reverse voltage and case temperature (°C) = 25.

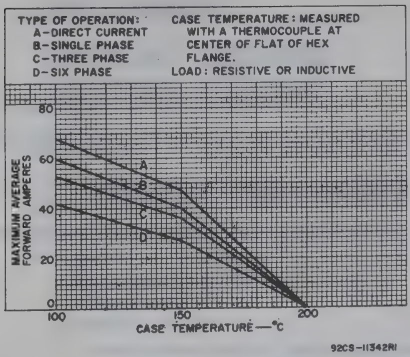


Fig.1– Rating chart for all types and corresponding reverse-polarity versions.

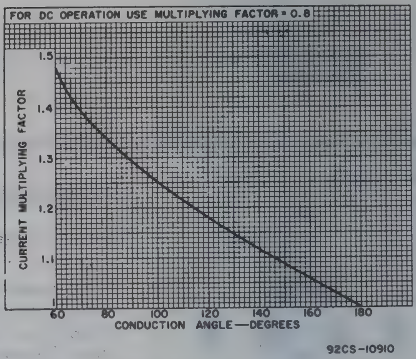


Fig.2– Current-multiplying-factor chart for polyphase and dc operation for all types and corresponding reverse-polarity versions.

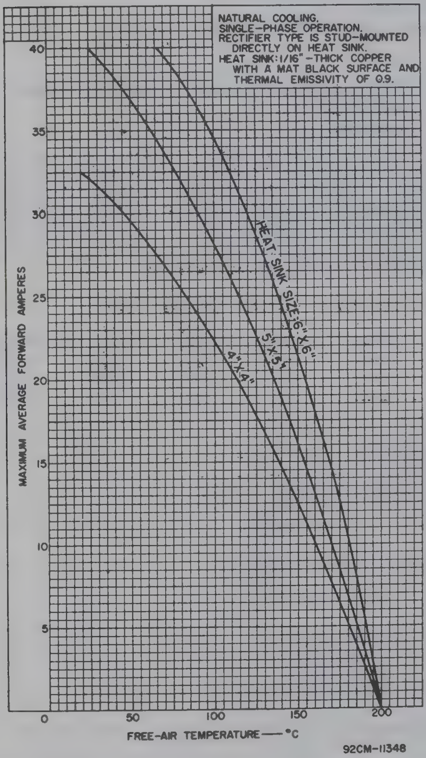


Fig.3– Operation guidance chart for all types and corresponding reverse-polarity versions.

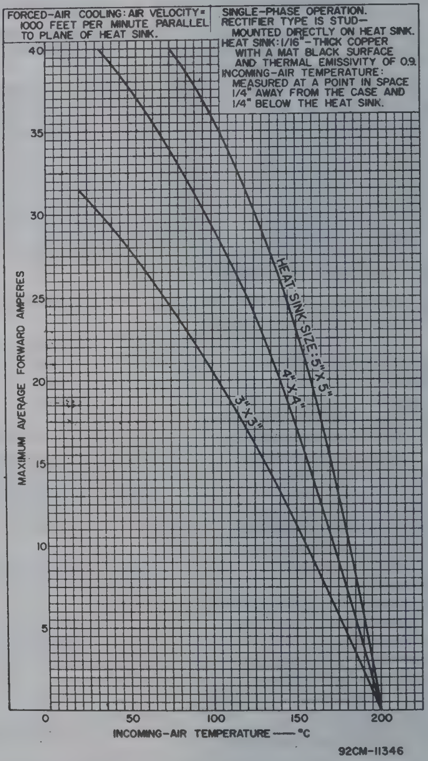


Fig.4– Operation guidance chart for all types and corresponding reverse-polarity versions.

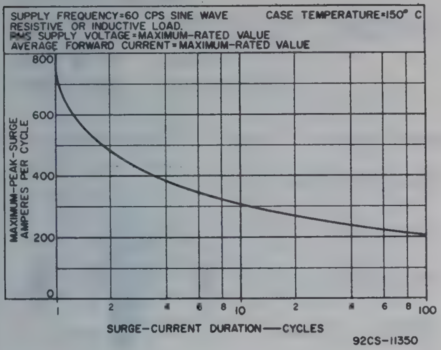


Fig.5– Surge-current rating chart for all types and corresponding reverse-polarity versions.

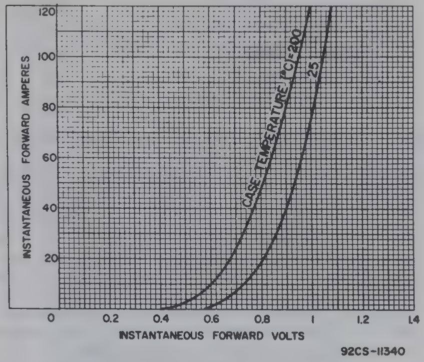


Fig.6– Typical forward characteristics for all types and corresponding reverse-polarity versions.

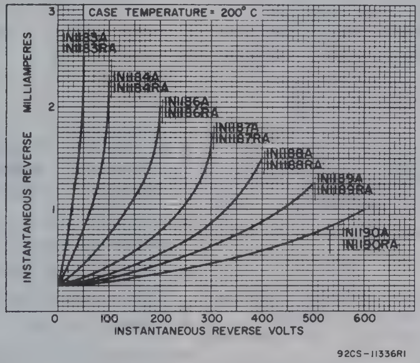


Fig.7– Typical reverse characteristics for all types and corresponding reverse-polarity versions.

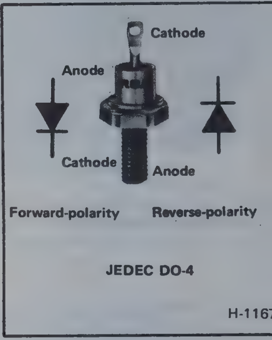
RCA
Solid State Division

Rectifiers

1N1199A 1N1200A 1N1202A 1N1203A 1N1204A 1N1205A 1N1206A

Used in generator-type power supplies for mobile equipment; in dc-to-dc converters, battery chargers, and machine-tool controls; in power supplies for aircraft, marine, and missile equipment, for dc motors, transmitters, rf generators, welding equipment, and electroplating systems; in dc-blocking service, and in a wide variety of other applications in military and industrial equipment.

Stud-Mounted Types for Industrial and Military Power Supplies



HALF-WAVE RECTIFIER SERVICE

Absolute-Maximum Ratings *for Supply Frequency of 60 Hz, Single-Phase Operation, and with Resistive or Inductive Load*

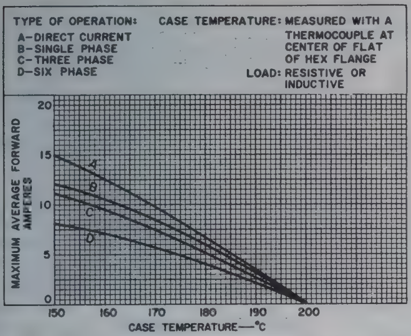
	1N1199-A	1N1200-A	1N1202-A	1N1203-A	1N1204-A	1N1205-A	1N1206-A
PEAK REVERSE VOLTS	50	100	200	300	400	500	600
TRANSIENT REVERSE VOLTS, NON-REPETITIVE (5-msec max. duration and case temperature range of 0 to 200° C)	100	200	350	450	600	700	800
RMS SUPPLY VOLTS	35	70	140	212	284	355	424
DC BLOCKING VOLTS	50	100	200	300	400	500	600
AVERAGE FORWARD AMPERES:							
At 150° C case temperature	12	12	12	12	12	12	12
At other case temperatures	See Fig. 1						
PEAK RECURRENT AMPERES	50	50	50	50	50	50	50
PEAK SURGE AMPERES:♦							
One-half cycle, sine wave	240	240	240	240	240	240	240
For one or more than one cycle	See Fig. 4						
CASE-TEMPERATURE RANGE: Operating and Storage	-65 to +200° C						
STUD TORQUE:							
Recommended	15 in-lb						
Maximum (DO NOT EXCEED)	25 in-lb						
Characteristics:							
Max. Forward Voltage Drop▲ (Volts)	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Max. Reverse Current (Ma.):							
Dynamic▲	3	2.5	2	1.75	1.5	1.25	1
Static●	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Max. Thermal Resistance, Junction-to-Case	2°C/Watt						

- available in reverse-polarity versions
  1N1199-RA, 1N1200-RA, 1N1202-RA, 1N1203-R
  1N1204-RA, 1N1205-RA, 1N1206-RA
- designed to meet stringent military mechani and environmental specifications
- diffused-junction process — exceptional u formity and stability of characteristics
- hermetic seals
- welded construct
- low thermal resistance
- low leakage curr
- low forward voltage drop
- JEDEC DO-4 outl
- high output current:
  up to 30 amperes — 6 rectifiers in 3-pha full-wave bridge circuit
  up to 24 amperes — 4 rectifiers in singl phase full-wave bridge circuit

♦ Superimposed on device operating within maximum voltage, current, and temperature ra and may be repeated after sufficient time elapsed for the device to return to the pre thermal-equilibrium conditions.

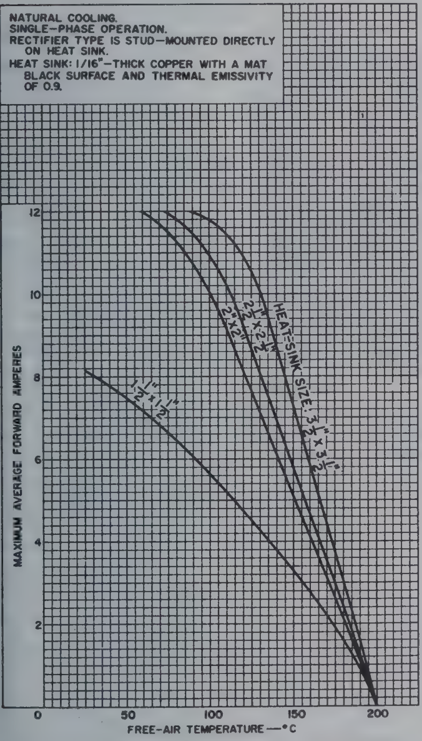
▲ Average value for one complete cycle at case perature of 150° C and at maximum rated vol and average forward current.

● DC value, at maximum peak reverse voltage, and case temperature (°C) = 25.



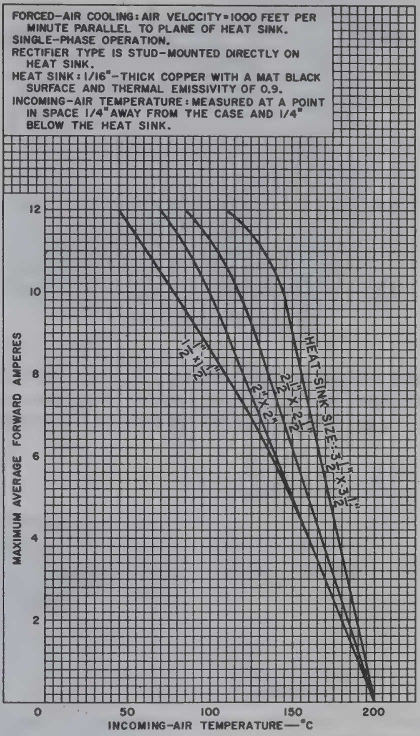
92CS-11065R1

Fig.1 - Rating Chart for all Types.



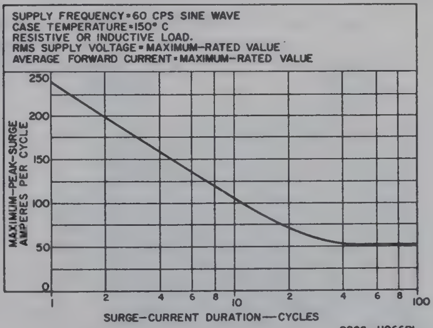
92CM-11068R1

Fig.2 - Operation Guidance Chart for all Types and corresponding reverse-polarity versions.



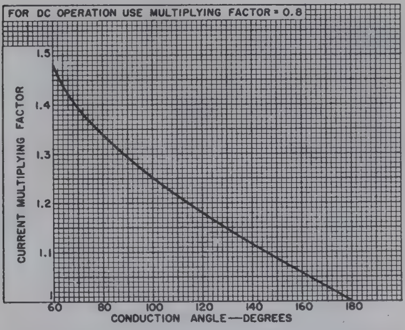
92CM-11067R1

Fig.3 - Operation Guidance Chart for all Types and corresponding reverse-polarity versions.



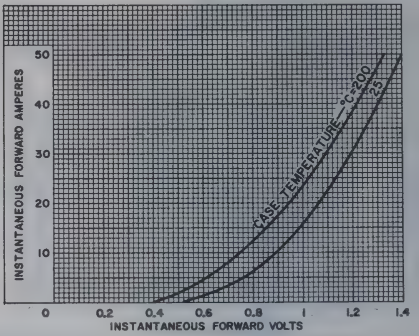
92CS-11066R1

Fig.4 - Peak-Surge-Current Rating Chart for all Types and corresponding reverse-polarity versions.



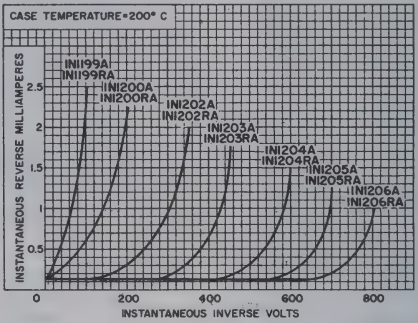
92CS-10910

Fig.5 - Current-Multiplying-Factor Chart for Polyphase and DC operation for all Types and corresponding reverse-polarity versions.



92CS-11063

Fig.6 - Typical Forward Characteristics fo all Types and corresponding reverse-polarity versions.



92CS-11064R2

Fig.7 - Typical Reverse Characteristics for all Types and corresponding reverse-polarity versions.

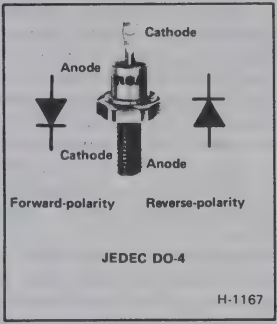
RCA
Solid State
Division

Rectifiers

1N1341B 1N1342B 1N1344B 1N1345B 1N1346B 1N1347B 1N1348B

Stud-Mounted

Types for Industrial Power Supplies



These silicon rectifiers are intended for use in generator-type power supplies for mobile equipment; in dc-to-dc converters, power supplies for dc motors, transmitters, rf generators, welding equipment, and electroplating systems; in dc-blocking service, magnetic amplifiers, and in a wide variety of other applications in industrial equipment.

HALF-WAVE RECTIFIER SERVICE

Absolute-Maximum Ratings for Supply Frequency of 60 Hz, Single-Phase Operation with Resistive or Inductive Load

	1N1341B	1N1342B	1N1344B	1N1345B	1N1346B	1N1347B	1N1348B
PEAK REVERSE VOLTS	50	100	200	300	400	500	600
TRANSIENT REVERSE VOLTS, NON-REPETITIVE (5-msec max. duration and case temperature range of 0 to 200° C.	100	200	350	450	600	700	800
RMS SUPPLY VOLTS	35	70	140	212	284	355	424
DC BLOCKING VOLTS	50	100	200	300	400	500	600
AVERAGE FORWARD AMPERES:							
At 150° C case temperature	6	6	6	6	6	6	6
At other case temperatures	See Fig.1						
PEAK RECURRENT AMPERES	25	25	25	25	25	25	25
PEAK SURGE AMPERES:[a] One-half cycle, sine wave	160	160	160	160	160	160	160
CASE-TEMPERATURE RANGE: Operating and Storage	-65 to +200° C						
STUD TORQUE:							
Recommended	15 in-lb						
Maximum (DO NOT EXCEED)	25 in-lb						
Characteristics:							
Max. Forward Voltage Drop[b] (Volts)	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Max. Reverse Current (Ma.):							
Dynamic[b]	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Static[c]	0.004	0.004	0.004	0.004	0.004	0.004	0.004

- Available in reverse-polarity versions: 1N1341RB, 1N1342RB, 1N1344RB, 1N1345RB, 1N1346RB, 1N1347RB, 1N1348RB
- Designed to meet stringent mechanical and environmental specifications
- Diffused-junction process — exceptional uniformity and stability of characteristics
- Hermetic seals
- Welded construction
- Low thermal resistance
- Low leakage current
- Low forward voltage drop
- JEDEC DO-4 outline
- High output current:
  up to 15 amperes — 6 rectifiers in 3-phase, full-wave bridge circuit
  up to 12 amperes — 4 rectifiers in single-phase full-wave bridge circuit

RATING CHART

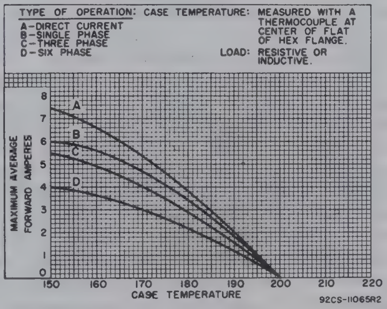


Fig.1

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[a] Superimposed on device operating within the maximum voltage, current, and temperature ratings and may be repeated after sufficient time has elapsed for the device to return to the presurge thermal-equilibrium conditions.

[b] Average value for one complete cycle at case temperature of 150° C and at maximum rated voltage and average forward current.

[c] DC value, at maximum peak reverse voltage, and case temperature (°C) = 25.

RCA
Solid State Division

Rectifiers

1N1763A
1N1764A

RCA-1N1763A and 1N1764A are hermetically sealed silicon rectifiers of the diffused-junction type, designed for use in power supplies of color and black-and-white television receivers, radio receivers, phonographs, high-fidelity amplifier systems, and other electronic equipment for commercial and industrial applications.

RCA-1N1763A and 1N1764A supersede and are unilaterally interchangeable with RCA-1N1763 and 1N1764, respectively. The new rectifiers incorporate all of the superior performance and reliability features which have gained industry acceptance for their RCA prototypes, and, in addition, offer substantially higher dc-output-current capabilities, lower reverse (leakage) currents, lower forward voltage drop, and a wider operating-temperature range.

Both devices have dc forward-current ratings of 1 ampere — resistive or inductive load, and 0.75 ampere — capacitive load at free-air temperatures up to 75°C (natural convection cooling). They can provide dc output currents of up to 2 amperes to capacitive loads when attached to simple heat sinks.

RCA-1N1763A has a peak-reverse-voltage rating of 400 volts, and is intended for applications in which the rectifier operates directly from an ac power line supplying up to 140 volts rms for capacitive loads, or up to 280 volts rms for resistive or inductive loads.

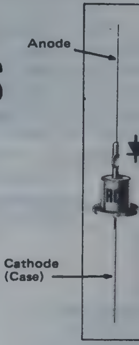
RCA-1N1764A has a peak-reverse-voltage rating of 500 volts, and is intended for applications in which the rectifier operates from an ac line through a step-up transformer supplying up to 175 volts rms for capacitive loads, or up to 350 volts rms for resistive or inductive loads.

RCA-1N1763A and 1N1764A have an operating-temperature range of -65°C to +135°C. They utilize the JEDEC DO-1 flanged-case, axial-lead package which provides flexibility of installation in both hand-wired and printed-circuit equipment designs. These new rectifiers, like their RCA prototypes, are conservatively rated and incorporate the following design features: (1) welded, hermetically sealed case for protection against moisture and contamination; (2) superior junction characteristics made possible by a precisely controlled diffusion process; (3) extensive and rigorous quality-control procedures.

DIFFUSED-JUNCTION SILICON RECTIFIERS

Flanged-Case Axial-Lead Types

For Power-Supply Applications In Commercial and Industrial Electronic Equipment



H-
JEDEC D

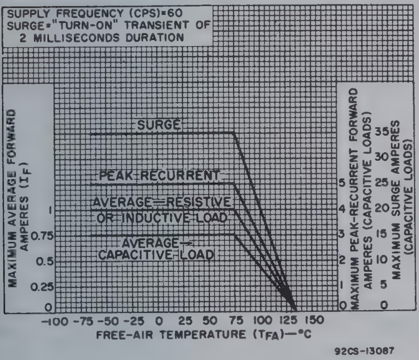
Features:

- high dc-output-current capability:
  - a) with natural convection cooling:
    1 ampere - resistive or inductive load } to 75°
    3/4 ampere - capacitive load } T_{FA}
  - b) with simple heat sinks:
    2 amperes - capacitive load } to 105°C T_C
    up to 2 amperes - capacitive load } to 75°C T_{FA}
- low dc reverse (leakage) currents:
  5 μa max. at 25°C; 100 μa max. at 75°
- low forward voltage drop:
  1.2 volts max. at a dc forward curren
  of 1 ampere
- wide operating-temperature range:
  -65°C to +135°C
- hermetically sealed JEDEC DO-1 packag
- unilaterally interchangeable with Type
  1N1763 and 1N1764

RECTIFIER SERVICE

bsolute-Maximum Ratings, *for a Supply Frequency of 60 cps:*

	Type 1N1763A		Type 1N1764A			
EAK REVERSE VOLTAGE.	400		500		max.	volts
MS SUPPLY VOLTAGE:						
For operation with resistive or inductive loads	280		350		max.	volts
For operation with capacitive loads	140		175		max.	volts
	At Free-Air Temperatures		*At Free-Air Temperatures*			
	Up to 75°C	*Above 75°C*	*Up to 75°C*	*Above 75°C*		
ORWARD CURRENT:						
For operation with resistive or inductive loads:						
AVERAGE (DC).	1	See *Fig.1*	1	See *Fig.1*	max.	amp
For operation with capacitive loads:						
AVERAGE (DC).	0.75	See *Fig.1*	0.75	See *Fig.1*	max.	amp
PEAK RECURRENT.	5		5		max.	amp
SURGE, for "turn-on" transient of 2 milliseconds duration	35		35		max.	amp
EMPERATURE RANGE (FREE-AIR):						
Operating	-65 to +135		-65 to +135			°C
Storage	-65 to +150		-65 to +150			°C



ig.1 - Rating Chart for RCA-1N1763A and 1N1764A

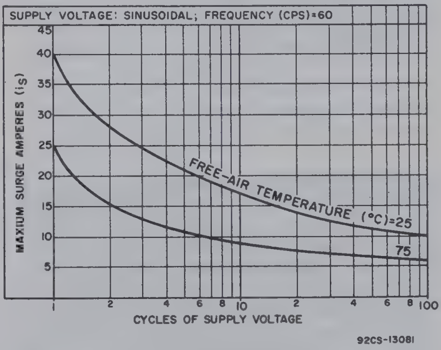


Fig.2 - Repetitive Surge Current Rating Chart for RCA-1N1763A and 1N1764A

Characteristics, *at a Free-Air Temperature of 25°C:*

	Type 1N1763A	Type 1N1764A	
Maximum Instantaneous Forward Voltage at an Instantaneous Forward Current of 1 ampere. . . .	1.2	1.2	volts
Maximum DC Reverse Current;			
At a Peak Reverse Voltage of 400 volts	5	-	µa
At a Peak Reverse Voltage of 500 volts	-	5	µa

Characteristics, *at a Free-Air Temperature of 75°C:*

Maximum DC Reverse Current:			
At a Peak Reverse Voltage of 400 volts	0.1	-	ma
At a Peak Reverse Voltage of 500 volts	-	0.1	ma

Typical Performance Characteristics, *at a Free-Air Temperature of 25°C:*

	Type 1N1763A			Type 1N1764A			
Half-Wave Rectifier Service:							
RMS Supply Voltage.	117	117	117	150	150	150	volts
Filter-Input Capacitor (C).	100	200	350	100	200	350	µF
Surge-Limiting Resistance[#].	5.6	5.6	5.6	6.8	6.8	6.8	ohms
DC Output Voltage at Input to Filter (Approx.):							
At half-load current of 375 ma.	140	145	150	180	185	190	volts
At full-load current of 750 ma.	125	130	140	155	160	170	volts
Voltage Regulation (Approx.):							
Half-load current to full-load current. .	15	15	10	25	25	20	volts
Half-Wave Voltage-Doubler Service:							
RMS Supply Voltage.	117	117	117	150	150	150	volts
Filter-Input Capacitor (C).	100	200	350	100	200	350	µF
Surge-Limiting Resistance[#].	5.6	5.6	5.6	6.8	6.8	6.8	ohms
DC Output Voltage at Input to Filter (Approx.):							
At half-load current of 375 ma.	255	265	275	325	340	350	volts
At full-load current of 750 ma.	225	240	255	285	305	325	volts
Voltage Regulation (Approx.):							
Half-load current to full-load current. .	30	25	20	40	35	25	volts
Full-Wave Voltage-Doubler Service:							
RMS Supply Voltage.	117	117	117	150	150	150	volts
Filter-Input Capacitor (C).	100	200	350	100	200	350	µF
Surge-Limiting Resistance[#].	5.6	5.6	5.6	6.8	6.8	6.8	ohms
DC Output Voltage at Input to Filter (Approx.):							
At half-load current of 375 ma.	275	280	290	350	355	365	volts
At full-load current of 750 ma.	250	260	275	320	330	345	volts
Voltage Regulation (Approx.):							
Half-load current to full-load current. .	25	20	15	30	25	20	volts

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[#] The transformer series resistance or other resistance in the rectifier supply circuit may be deducted from the value shown.

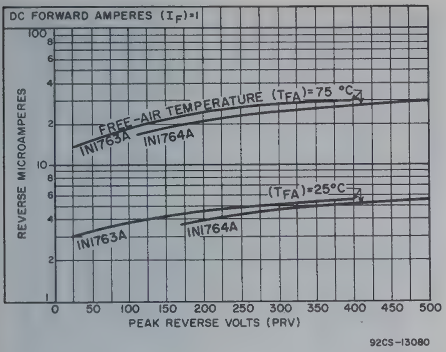


Fig.3 - Typical Dynamic Reverse Current Characteristics for RCA-1N1763A and 1N1764A.

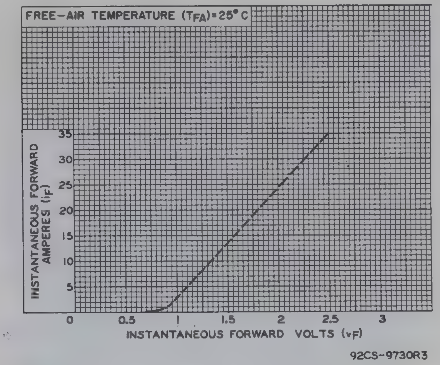


Fig.4 - Typical Forward Voltage and Current Characteristics for RCA-1N1763A and 1N1764A.

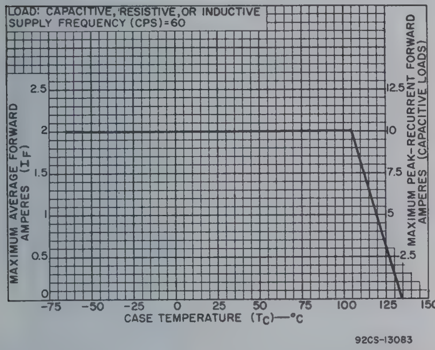
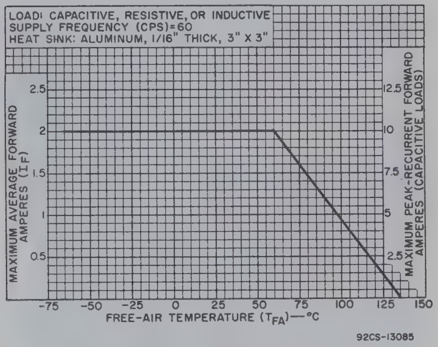
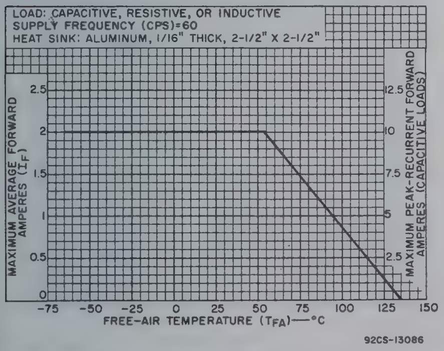


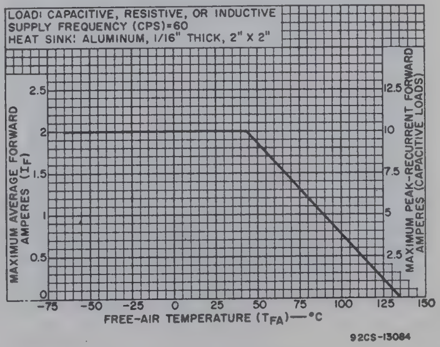
Fig.5 - Forward-Current Capabilities of RCA-1N1763A and 1N1764A for Operation with Heat Sink at Case Temperatures from -65°C to +135°C.



a) 3" x 3" Heat Sink.

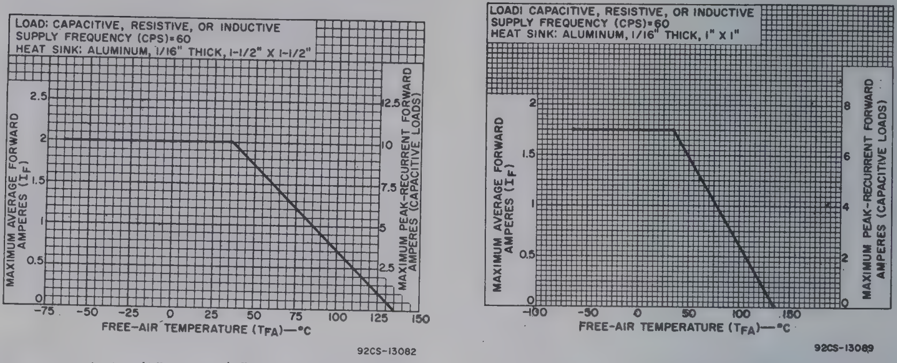


b) 2-1/2" x 2-1/2" Heat Sink.



c) 2" x 2" Heat Sink.

Figs.6a,6b,and 6c — Forward-Current Capabilities of RCA-1N1763A and 1N1764A for Operation with Heat Sinks.



d) 1-1/2" x 1-1/2" Heat Sink.

e) 1" x 1" Heat Sink.

Figs. 6d and 6e - Forward-Current Capabilities of RCA-1N1763A and 1N1764A for Operation with Heat Sinks.

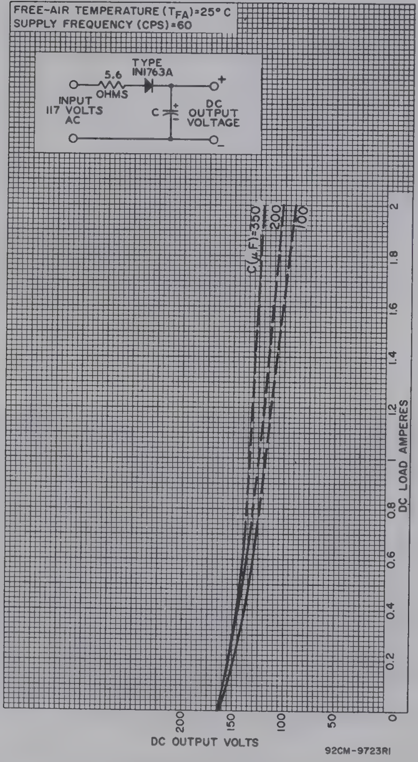


Fig.7 - Typical Operation Characteristics for RCA-1N1763A in Half-Wave Rectifier Service.

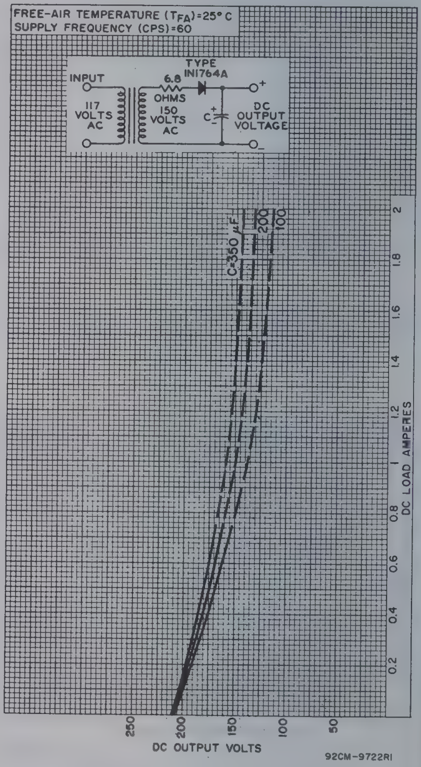


Fig.8 - Typical Operation Characteristics for RCA-1N1764A in Half-Wave Rectifier Service.

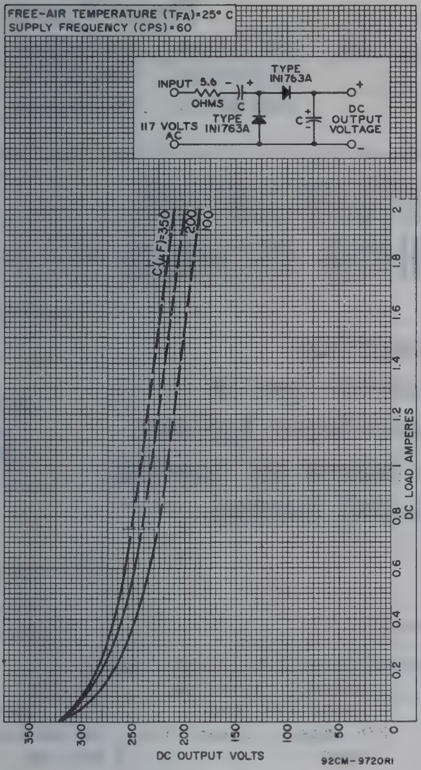


Fig.9 - Typical Operation Characteristics of RCA-1N1763A in Half-Wave Voltage-Doubler Service.

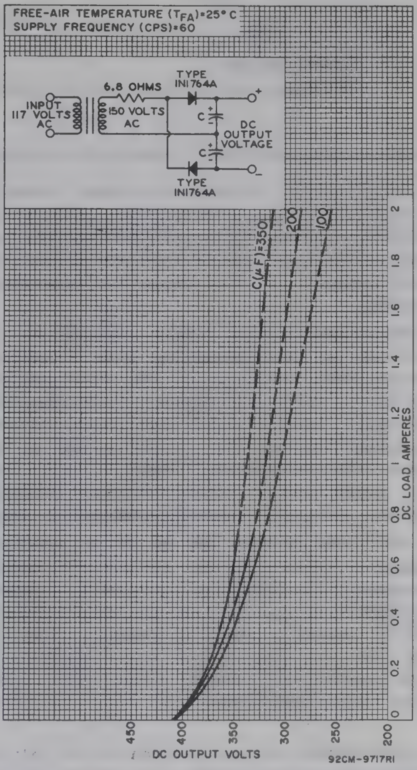


Fig.10 - Typical Operation Characteristics of RCA-1N1764A in Full-Wave Voltage-Doubler Service.

RCA
Solid State
Division

Rectifiers

1N2858A 1N2859A 1N2862A
1N2860A 1N2863A
1N2861A 1N2864A

RCA-1N2858A, 1N2859A, 1N2860A, 1N2861A, 1N2862A, 1N2863A, and 1N2864A are hermetically sealed silicon rectifiers of the diffused-junction type, designed for use in a variety of applications in industrial and commercial electronic equipment.

RCA-1N2858A through 1N2864A supersede and are unilaterally interchangeable with RCA-1N2858 through 1N2864, respectively. The new rectifiers incorporate all of the superior performance and reliability features which have gained industry acceptance for their RCA prototypes, and, in addition, offer substantially higher dc output-current capabilities, lower reverse (leakage) currents, and a wider operating-temperature range.

All seven of these new rectifier types have maximum dc-forward-current ratings of 1 ampere for resistive or inductive loads and 0.75 ampere for capacitive loads at free-air temperatures up to 75°C (natural convection cooling). They are also capable of providing dc output currents of up to 2 amperes with capacitive loads when attached to simple heat sinks.

RCA-1N2858A through 1N2864A differ only in peak-reverse-voltage ratings (see Maximum Ratings chart). They are rated for operation at free-air temperatures from -65° to +135°C, and utilize the JEDEC DO-1 flange-type, axial-lead rectifier package which provides flexibility of installation in both hand-wired and printed-circuit equipment designs.

These new rectifiers, like their RCA prototypes, are conservatively rated, and incorporate the following design features and special tests which contribute to their outstanding performance and reliability: (1) junctions of extremely high uniformity produced by a special, precisely controlled diffusion process, (2) rugged internal mount structure, (3) hermetically sealed cases, (4) prolonged treatment at high temperatures to stabilize characteristics, (5) pressure tests of seals for protection against moisture and contamination, (6) tests for forward and reverse characteristics at 25°C, and (7) high-temperature dynamic tests under full-load conditions.

DIFFUSED-JUNCTION SILICON RECTIFIERS

Flanged-Case Axial-Lead Types For General-Purpose Applications In Industrial And Commercial Electronic Equipment

Anode
Cathode
(Case)

H-96
JEDEC DO-

Features:

- high dc-output-current capability:
  1 ampere - resistive or inductive load; 3/4 ampere - capacitive load } to 75°C with natural convection cooling
  up to 2 amperes - capacitive load } to 105°C with simple heat sinks
- low dynamic reverse current:
  0.1 ma max. at 50°C
  0.3 ma max. at 75°C
- low dc forward voltage drop:
  1.2 volts max. at 25°C with 1 ampere dc forward current
- wide operating-temperature range:
  -65° to +135°C
- hermetically sealed JEDEC DO-1 package
- unilaterally interchangeable with Types 1N2858 through 1N2864
- specially processed and tested for high reliability and stability of characteristics

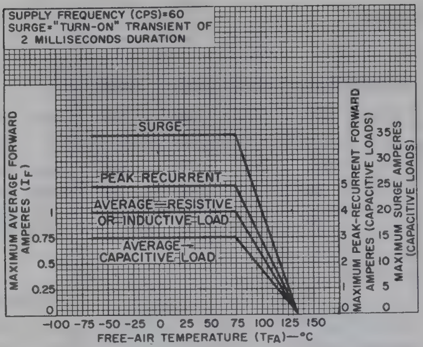
RECTIFIER SERVICE

bsolute-Maximum Ratings, *for a Supply Frequency of 60 cps:*

	IN2858A	IN2859A	IN2860A	IN2861A	IN2862A	IN2863A	IN2864A	
EAK REVERSE VOLTAGE	50	100	200	300	400	500	600	max. volts
MS SUPPLY VOLTAGE:								
For resistive or inductive loads	35	70	140	210	280	350	420	max. volts
For capacitive loads	17	35	70	105	140	175	210	max. volts
C REVERSE (BLOCKING) VOLTAGE	50	100	200	300	400	500	600	max. volts
ORWARD CURRENT:								
For resistive or inductive loads:								
AVERAGE (DC) At T_{FA} up to 75°C	1	1	1	1	1	1	1	max. amp
AVERAGE (DC) At T_{FA} above 75°C	See *Fig.1*							
For capacitive loads:								
AVERAGE (DC) At T_{FA} up to 75°C	0.75	0.75	0.75	0.75	0.75	0.75	0.75	max. amp
AVERAGE (DC) At T_{FA} above 75°C	See *Fig.1*							
PEAK RECURRENT At T_{FA} up to 75°C	5	5	5	5	5	5	5	max. amp
PEAK RECURRENT At T_{FA} above 75°C	See *Fig.1*							
SURGE, for "turn-on" transient of 2 milliseconds duration:								
At T_{FA} up to 75°C	35	35	35	35	35	35	35	max. amp
At T_{FA} above 75°C	See *Fig.1*							
SURGE, repetitive, at T_{FA} = 25°C:								
For one cycle of supply voltage	40	40	40	40	40	40	40	max. amp
For more than one cycle of supply voltage	See *Fig.2*							
TEMPERATURE RANGE (FREE-AIR)								
Operating	-65 to +135							°C
Storage	-65 to +150							°C

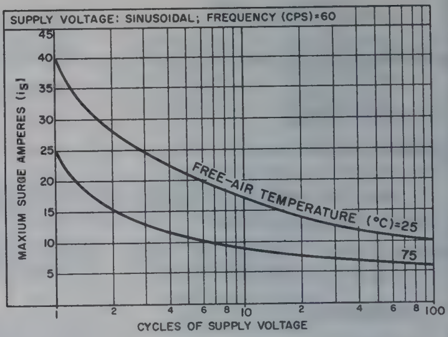
haracteristics:

	IN2858A	IN2859A	IN2860A	IN2861A	IN2862A	IN2863A	IN2864A	
aximum Forward Voltage Drop (DC) at I_F = 1 Ampere, T_{FA} = 25°C	1.2	1.2	1.2	1.2	1.2	1.2	1.2	volts
aximum Dynamic Reverse Current (Averaged over 1 Complete Cycle of Supply Voltage): at Maximum Rated PRV:								
T_{FA} = 50°C	0.1	0.1	0.1	0.1	0.1	0.1	0.1	ma
T_{FA} = 75°C	0.3	0.3	0.3	0.3	0.3	0.3	0.3	ma



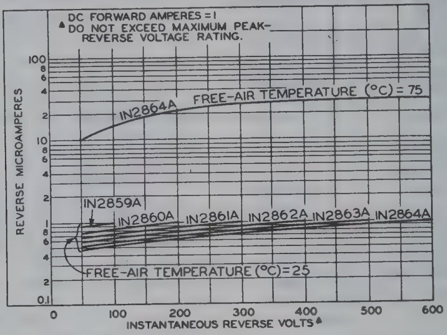
92CS-13087

Fig. 1 - Rating Chart for RCA-1N2858A through 1N2864A



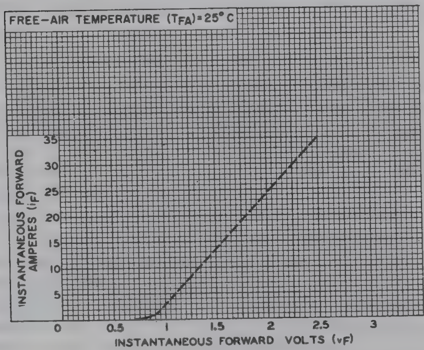
92CS-13081

Fig. 2 - Repetitive Surge Current Rating Chart for RCA-1N2858A through 1N2864A.



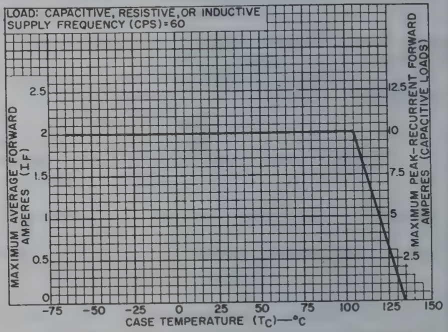
92CS-10477R1

Fig. 3 - Typical Dynamic Reverse Characteristics for RCA-1N2858A through 1N2864A.



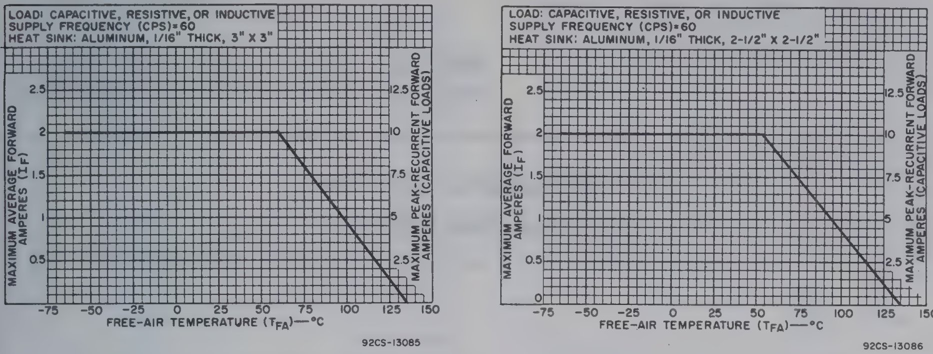
92CS-9730R3

Fig. 4 - Typical Forward Voltage and Current Characteristic for RCA-1N2858A through 1N2864A.



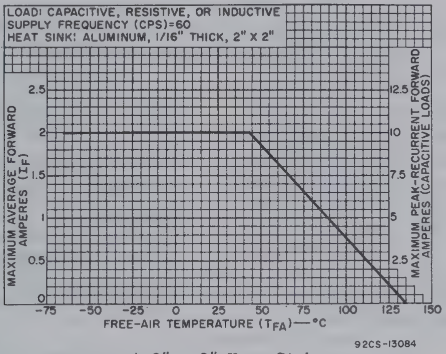
92CS-13083

Fig. 5 - Forward-Current Capabilities of RCA-1N2858 through 1N2864A for Operation with Heat Sink at Case Temperatures from -65°C to +135°C.

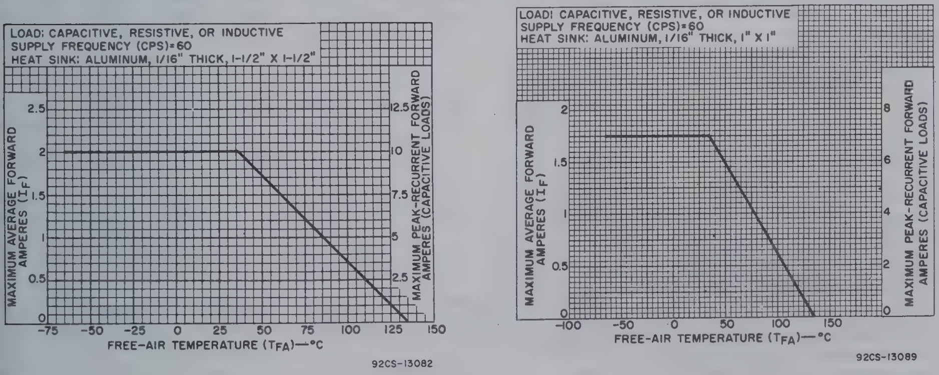


a) 3" x 3" Heat Sink.

b) 2-1/2" x 2-1/2" Heat Sink.



c) 2" x 2" Heat Sink.



d) 1-1/2" x 1-1/2" Heat Sink.

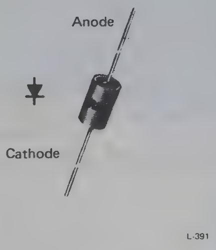
e) 1" x 1" Heat Sink.

Figs.6a, 6b, 6c, 6d, and 6e - Forward-Current Capabilities of RCA-1N2858A through 1N2864A for Operation with Heat Sinks.

RCA
Solid State Division

Rectifiers

1N3255
1N3193 1N3195 1N3253 1N3256
1N3194 1N3196 1N3254 1N3563



JEDEC DO-26

Diffused-Junction Silicon Rectifiers

For Industrial and Consumer-Product Applications

Features:

- Cylindrical design with axial leads for simple handling and installation
- Compact, hermetically sealed metal case (0.405″ max. length; 0.240″ max. dia.)
- Insulated types 1N3253, 1N3254, 1N3255, 1N3256, and 1N3563 have transparent, high-dielectric-strength plastic sleeve over metal case
- High maximum forward-current ratings — up to 750 milli amperes at 75 °C
- Peak-reverse-voltage ratings — 200 to 1000 volts
- Maximum free-air operating temperature — 100 °C
- Designed to meet stringent temperature-cycling and humidity requirements of critical industrial and consumer-product applications

RCA-1N3193, 1N3194, 1N3195, 1N3196, 1N3253, 1N3254, 1N3255, 1N3256, and 1N3563 are hermetically sealed silicon rectifiers of the diffused-junction type utilizing small cylindrical metal cases and axial leads. Types 1N3253, 1N3254, 1N3255, and 1N3256 are insulated versions of types 1N3193, 1N3194, and 1N3196, respectively. Type 1N3563 is an insulated rectifier which does not have an uninsulated equivalent.

RECTIFIER SERVICE (For a supply-line frequency of Hz)

MAXIMUM RATINGS, *Absolute-Maximum Values:*

	For resistive or inductive load					*For capacitor-input filter*					
	1N3193 1N3253	1N3194 1N3254	1N3195 1N3255	1N3196 1N3256	1N3563	1N3193 1N3253	1N3194 1N3254	1N3195 1N3255	1N3196 1N3256	1N3563	
PEAK REVERSE VOLTAGE	200	400	600	800	1000	200	400	600	800	1000	vol
RMS SUPPLY VOLTAGE	140	280	420	560	700	70	140	210	280	350	vol
FORWARD CURRENT:											
For free-air temperatures up to 75°C. For free-air temperatures above 75°C, see Rating Chart.											
DC	750	750	750	500	400	500	500	500	400	300	m
PEAK RECURRENT	—	—	—	—	—	6	6	6	5	4	am
SURGE — For "turn-on" time of 2 milliseconds	—	—	—	—	—	35	35	35	35	35	am
FREE-AIR-TEMPERATURE RANGE:											
Operating	← -65 to +100 →										°C
Storage	← -65 to +175 →										°C
LEAD TEMPERATURE:											
For 10 seconds maximum	← 255 →										°C

Characteristics, *At a Free-Air Temperature of 25°C:*

	1N3193 1N3253	1N3194 1N3254	1N3195 1N3255	1N3196 1N3256	1N3563	
Maximum Instantaneous Forward Voltage Drop at dc forward current of 0.5 ampere	1.2	1.2	1.2	1.2	1.2	vol
Maximum Reverse Current:						
Dynamic, at T_{FA} = 75°C*	0.2	0.2	0.2	0.2	0.2	m
Static, at T_{FA} = 25°C**	0.005	0.005	0.005	0.005	0.005	m

---

*At max. peak reverse voltage and max. dc forward current.

**At max. peak reverse voltage and zero forward current.

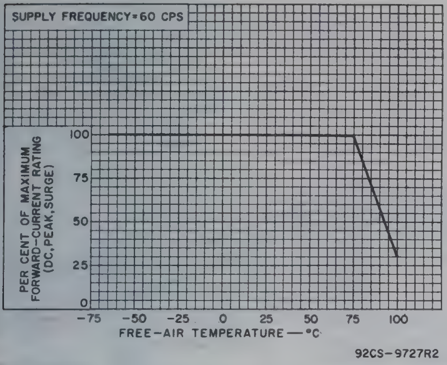


Fig.1— Rating chart for types 1N3193 to 1N3196, 1N3253 to 1N3256, and 1N3563.

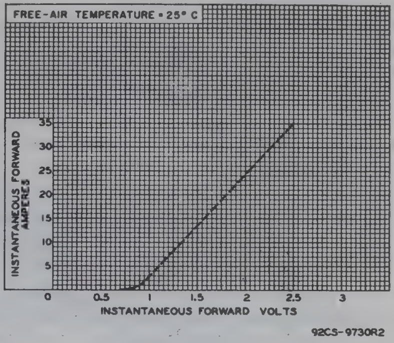


Fig.2— Typical forward characteristics for types 1N3193 to 1N3196, 1N3253 to 1N3256, and 1N3563.

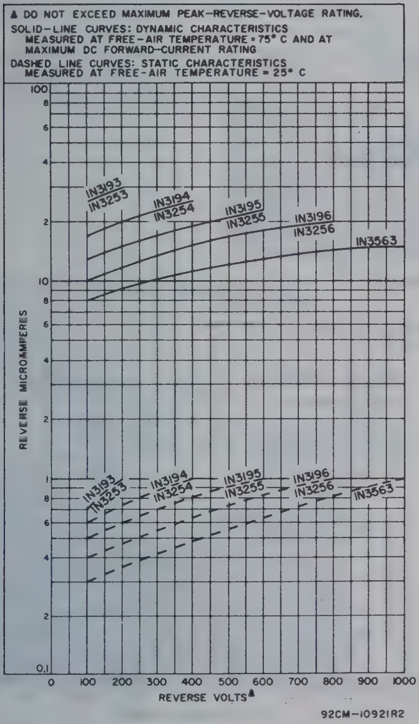


Fig.3— Typical reverse characteristics for types 1N3193 to 1N3196, 1N3253 to 1N3256, and 1N3563.

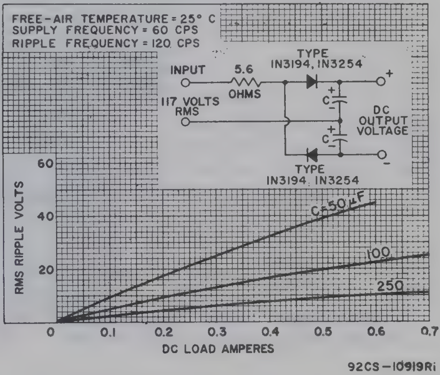


Fig.4— Typical operation characteristics of types 1N3194 and 1N3254 in full-wave voltage-doubler service.

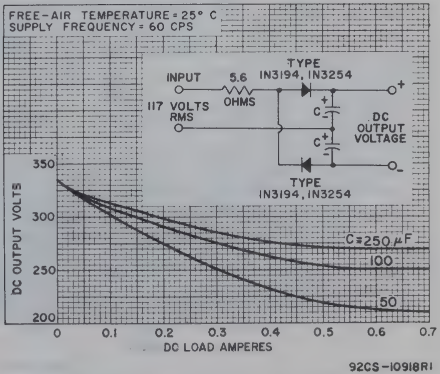


Fig.5— Typical operation characteristics of types 1N3194 and 1N3254 in full-wave voltage-doubler service.

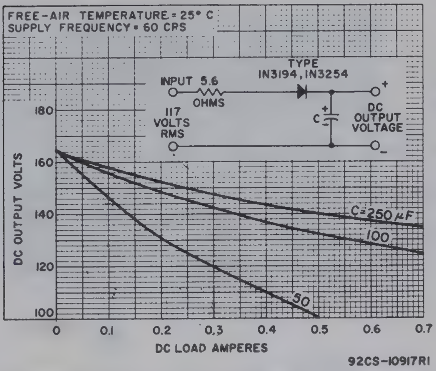


Fig.6— Typical operation characteristics of types 1N3194 and 1N3254 in half-wave rectifier service.

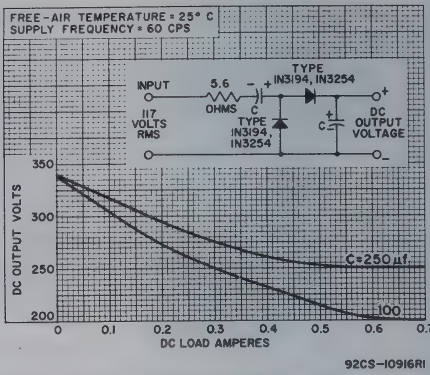


Fig.7— Typical operation characteristics of types 1N3194 an 1N3254 in half-wave voltage-doubler service.

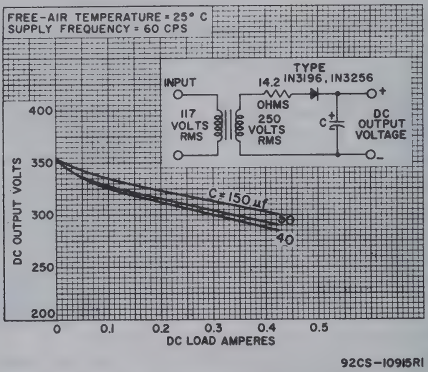


Fig.8— Typical operation characteristics of types 1N3196 and 1N3256 in half-wave rectifier service.

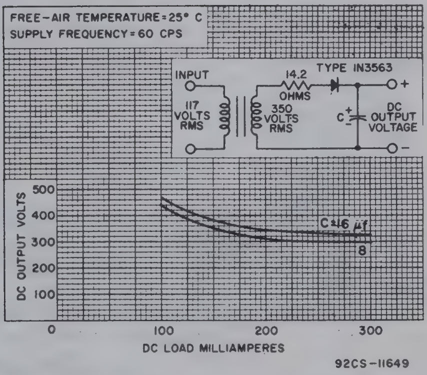


Fig.9— Typical operation characteristics of type 1N3563 in half-wave rectifier service.

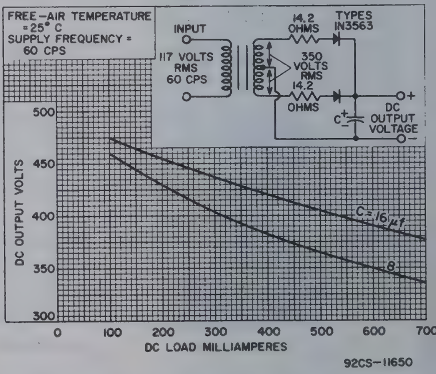
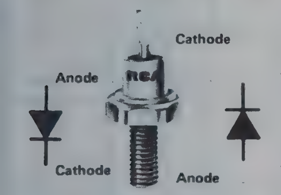


Fig.10—Typical operation characteristics of type 1N3563 in fu wave rectifier service.

RCA
Solid State Division

Rectifiers

1N3879–1N3883
1N3879R–1N3883R


Cathode
Anode
RCA
Cathode
Anode
Forward-polarity (1N3879-1N3883)
Reverse-polarity (1N3879R-1N3883R)

JEDEC DO-4

H-1167

6-A, 50-to-400-V, Fast-Recovery Silicon Rectifiers

General-Purpose Types for High-Current Applications

Features:

- Available in reverse-polarity versions: 1N3879R, 1N3880R, 1N3881R, 1N3882R, 1N3883R
- Fast reverse-recovery time (t_{rr}) – 200 ns max. (I_F = 1 A, I_{RM} = 2 A max., see test circuit Fig. 2)
- Low reverse-recovery current
- Low forward-voltage drop
- Low-thermal-resistance hermetic package

For data on other RCA fast recovery rectifiers, refer to the following RCA data bulletins:
6-A File No. 663 (D2406 Series)
12-A File No. 664 (D2412 Series)
20-A File No. 665 (D2520 Series)
40-A File No. 580 (D2540 Series)

CA types 1N3879 – 1N3883 and 1N3879R – 1N3883R are iffused-junction silicon rectifiers in a stud-type hermetic ackage. These devices differ only in their voltage ratings.

All types feature fast reverse-recovery time of 200 ns max. These devices are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications

		1N3879 1N3879R	1N3880 1N3880R	1N3881 1N3881R	1N3882 1N3882R	1N3883 1N3883R	
AXIMUM RATINGS, *Absolute-Maximum Values:*							
EVERSE VOLTAGE:							
Repetitive peak	V_{RRM}	50	100	200	300	400	V
Non-repetitive peak	V_{RSM}	75	200	300	400	500	V
DC (Blocking)	V_R	50	100	200	300	400	V
ORWARD CURRENT (Conduction angle = 180°, half sine wave):							
RMS (T_C = 100°C)▲	$I_{F(RMS)}$	9					A
Average (T_C = 100°C)▲	I_o	6					A
Peak-surge (non-repetitive):	I_{FSM}						
At junction temperature (T_J) = 150°C:							
For one cycle of applied voltage, 60 Hz		75					A
For ten cycles of applied voltage, 60 Hz		35					A
Peak (repetitive)	I_{FRM}	25					A
STORAGE-TEMPERATURE RANGE	T_{stg}	–65 to 175					°C
OPERATING (JUNCTION) TEMPERATURE	T_J	–65 to 150					°C
TUD TORQUE:	τ_s						
Recommended		15					in-lb
Maximum (DO NOT EXCEED)		25					in-lb

n accordance with JEDEC registration data.

Case temperature is measured at center of any flat surface on the hexagonal head of the mounting stud.

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS ALL TYPES MIN.	LIMITS ALL TYPES MAX.	UNITS
* Reverse Current:				
Static				
For V_{RRM} = max. rated value, $I_F = 0$, $T_C = 25°C$	I_{RM}	–	15	µA
$T_C = 100°C$		–	1	mA
Dynamic				
For single phase full cycle average, $I_o = 6$ A, $T_C = 100°C$	$I_{R(AV)}$	–	3	mA
* Instantaneous Forward Voltage Drop:				
At $i_F = 6$ A, V_{RRM} = rated value, $T_J = 100°C$	$v_{F(PK)}$	–	1.5	V
At $i_F = 6$ A, $T_J = 25°C$	v_F	–	1.4	V
* Reverse Recovery Time: For circuit shown in Fig. 2, at $I_{FM} = 1$ A, $I_{RM} = 2$ A max., $T_C = 25°C$	t_{rr}	–	200	ns
Thermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	2.5	°C/W

*In accordance with JEDEC registration data.

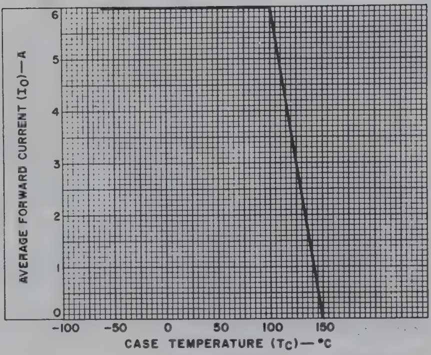
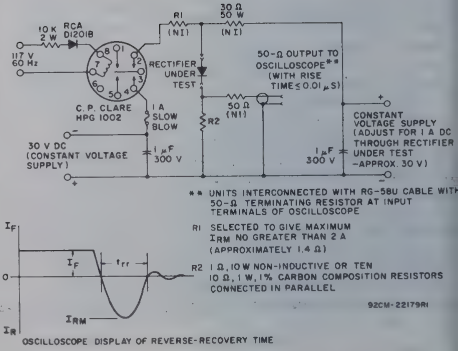


Fig.1 — Average forward current vs. case temperature.



10 K
2 W
RCA
D1201B
117 V
60 Hz
8
1
2
7
3
6
5
4
C. P. CLARE
HPG 1002
1 A
SLOW
BLOW
R1
(NI)
30 Ω
50 W
(N I)
RECTIFIER
UNDER
TEST
50-Ω OUTPUT TO
OSCILLOSCOPE**
(WITH RISE
TIME ≤ 0.01 µS)
50 Ω
(NI)
R2
30 V DC
(CONSTANT VOLTAGE
SUPPLY)
1 µF
300 V
1 µF
300 V
CONSTANT
VOLTAGE SUPPLY
(ADJUST FOR 1 A DC
THROUGH RECTIFIER
UNDER TEST
-APPROX. 30 V)
+
-
IF
IF
trr
0
IRM
IR
OSCILLOSCOPE DISPLAY OF REVERSE-RECOVERY TIME
92CM-22179R1

** UNITS INTERCONNECTED WITH RG-58U CABLE WIT
50-Ω TERMINATING RESISTOR AT INPUT
TERMINALS OF OSCILLOSCOPE

R1 SELECTED TO GIVE MAXIMUM I_{RM} NO GREATER THAN 2 A (APPROXIMATELY 1.4 Ω)

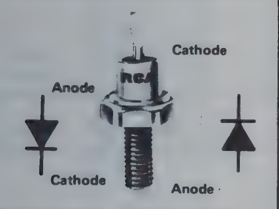
R2 1 Ω, 10 W NON-INDUCTIVE OR TEN 10 Ω, 1 W, 1% CARBON COMPOSITION RESISTORS CONNECTED IN PARALLEL

Fig. 2 — Test circuit (pulsed dc) for measurement of reverse-recovery time.

RCA
Solid State Division

Rectifiers

1N3889–1N3893
1N3889R–1N3893R



Forward-polarity (1N3889-1N3893)

Reverse-polarity (1N3889R-1N3893R)

JEDEC DO-4

H-1167

12-A, 50-to-400-V, Fast-Recovery Silicon Rectifiers

General-Purpose Types for High-Current Applications

Features:

- Available in reverse-polarity versions: 1N3889R, 1N3890R, 1N3891R, 1N3892R, 1N3893R
- Fast reverse-recovery time (t_{rr}) – 200 ns max. (I_F = 1 A, I_{RM} = 2 A max., see test circuit Fig. 2)
- Low reverse-recovery current
- Low forward-voltage drop
- Low-thermal-resistance hermetic package

For data on other RCA fast recovery rectifiers, refer to the following RCA data bulletins:

6-A File No. 663 (D2406 Series)
12-A File No. 664 (D2412 Series)
20-A File No. 665 (D2520 Series)
40-A File No. 580 (D2540 Series)

RCA types 1N3889 – 1N3893 and 1N3889R – 1N3893R are diffused-junction silicon rectifiers in a stud-type hermetic package. These devices differ only in their voltage ratings.

All types feature fast reverse-recovery time of 200 ns max. These devices are intended for use in high-speed inverters choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications

MAXIMUM RATINGS, *Absolute-Maximum Values:*		1N3889 1N3889R	1N3890 1N3890R	1N3891 1N3891R	1N3892 1N3892R	1N3893 1N3893R	
REVERSE VOLTAGE:							
*Repetitive peak	V_{RRM}	50	100	200	300	400	V
Non-repetitive peak	V_{RSM}	75	200	300	400	500	V
*DC (Blocking)	V_R	50	100	200	300	400	V
FORWARD CURRENT (Conduction angle = 180°, half sine wave):							
RMS (T_C = 100°C)▲	$I_{F(RMS)}$	18					A
* Average (T_C = 100°C)▲	I_o	12					A
* Peak-surge (non-repetitive):	I_{FSM}						
At junction temperature (T_J) = 150°C:							
For one cycle of applied voltage, 60 Hz		150					A
For ten cycles of applied voltage, 60 Hz		70					A
Peak (repetitive)	I_{FRM}	50					A
*STORAGE-TEMPERATURE RANGE	T_{stg}	–65 to 175					°C
*OPERATING (JUNCTION) TEMPERATURE	T_J	–65 to 150					°C
STUD TORQUE:	τ_s						
*Recommended		15					in-lb
Maximum (DO NOT EXCEED)		25					in-lb

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*In accordance with JEDEC registration data.

▲Case temperature is measured at center of any flat surface on the hexagonal head of the mounting stud.

ELECTRICAL CHARACTERISTICS

	CHARACTERISTIC	SYMBOL	LIMITS ALL TYPES MIN.	LIMITS ALL TYPES MAX.	UNITS
*	Reverse Current:				
	Static				
	For V_{RRM} = max. rated value, $I_F = 0$, $T_C = 25°C$	I_{RM}	–	25	μA
	$T_C = 100°C$		–	3	mA
	Dynamic				
	For single phase full cycle average, $I_o = 12$ A, $T_C' = 100°C$	$I_{R(AV)}$	–	5	mA
*	Instantaneous Forward Voltage Drop:				
	At $i_F = 12$ A, V_{RRM} = rated value, $T_J = 100°C$	$v_{F(PK)}$	–	1.5	V
	At $i_F = 12$ A, $T_J = 25°C$	v_F	–	1.4	V
*	Reverse Recovery Time:				
	For circuit shown in Fig. 2, at $I_{FM} = 1$ A, $I_{RM} = 2$ A max., $T_C = 25°C$	t_{rr}	–	200	ns
	Thermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	1.5	°C/W

*In accordance with JEDEC registration data.

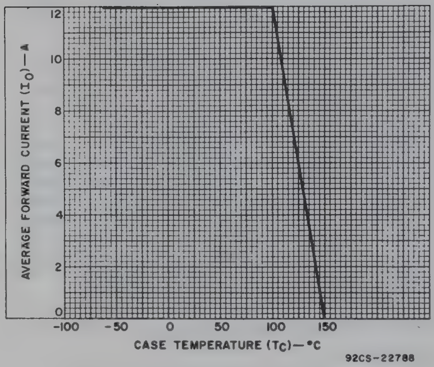


Fig. 1 – Average forward current vs. case temperature.

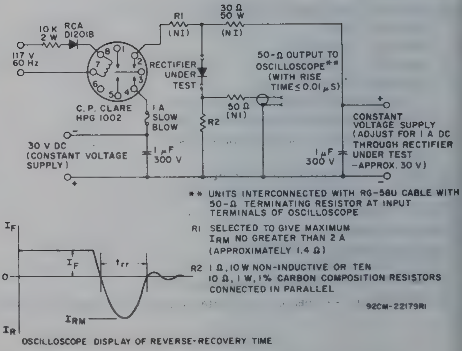
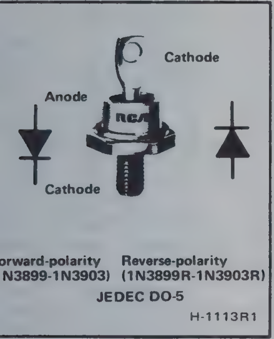

117 V
60 Hz
10 K
2 W
RCA
D1201B
1
2
3
4
5
6
7
8
C. P. CLARE
HPG 1002
R1
(NI)
30 Ω
50 W
(NI)
RECTIFIER
UNDER
TEST
50-Ω OUTPUT TO
OSCILLOSCOPE**
(WITH RISE
TIME≤0.01 μS)
50 Ω
(NI)
R2
1 A
SLOW
BLOW
30 V DC
(CONSTANT VOLTAGE
SUPPLY)
1 μF
300 V
1 μF
300 V
+
−
CONSTANT
VOLTAGE SUPPLY
(ADJUST FOR 1 A DC
THROUGH RECTIFIER
UNDER TEST
-APPROX. 30 V)
** UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE
R1 SELECTED TO GIVE MAXIMUM IRM NO GREATER THAN 2 A (APPROXIMATELY 1.4 Ω)
R2 1 Ω, 10 W NON-INDUCTIVE OR TEN 10 Ω, 1 W, 1% CARBON COMPOSITION RESISTORS CONNECTED IN PARALLEL
92CM-22179R1
IF
IF
trr
0
IRM
IR
OSCILLOSCOPE DISPLAY OF REVERSE-RECOVERY TIME

Fig.2 – Test circuit (pulsed dc) for measurement of reverse-recovery time.

RCA
Solid State Division

Rectifiers

1N3899–1N3903
1N3899R–1N3903R



20-A, 50-to-400-V, Fast-Recovery Silicon Rectifiers

General-Purpose Types for High-Current Applications

Features:

- Available in reverse-polarity versions: 1N3899R, 1N3900R, 1N3901R, 1N3902R, 1N3903R
- Fast reverse-recovery time (t_{rr}) – 200 ns max. (I_{RM} = 1 A, I_{RM} = 2 A max., see test circuit Fig. 2)
- Low reverse-recovery current
- Low forward-voltage drop
- Low-thermal-resistance hermetic package

For data on other RCA fast recovery rectifiers, refer to the following RCA data bulletins:

6-A File No. 663 (D2406 Series)
12-A File No. 664 (D2412 Series)
20-A File No. 665 (D2520 Series)
40-A File No. 580 (D2540 Series)

CA types 1N3899–1N3903 and 1N3899R–1N3903R are ffused-junction silicon rectifiers in a stud-type hermetic ckage. These devices differ only in their voltage ratings.

All types feature fast reverse-recovery time of 200 ns max. These devices are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications

		1N3899 1N3899R	1N3900 1N3900R	1N3901 1N3901R	1N3902 1N3902R	1N3903 1N3903R	
AXIMUM RATINGS, *Absolute-Maximum Values:*							
EVERSE VOLTAGE:							
Repetitive peak	V_{RRM}	50	100	200	300	400	V
Non-repetitive peak	V_{RSM}	75	200	300	400	500	V
DC (Blocking)	V_R	50	100	200	300	400	V
ORWARD CURRENT (Conduction angle = 180°, half sine wave):							
RMS (T_C = 100°C)▲	$I_{F(RMS)}$			30			A
Average (T_C = 100°C)▲	I_o			20			A
Peak-surge (non-repetitive):	I_{FSM}						
At junction temperature (T_J) = 150°C:							
For one cycle of applied voltage, 60 Hz				225			A
For ten cycles of applied voltage, 60 Hz				120			A
Peak (repetitive)	I_{FRM}			100			A
STORAGE-TEMPERATURE RANGE	T_{stg}			–65 to 175			°C
OPERATING (JUNCTION) TEMPERATURE	T_J			–65 to 150			°C
TUD TORQUE:	T_s						
Recommended				30			in-lb
Maximum (DO NOT EXCEED)				50			in-lb

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n accordance with JEDEC registration data.

Case temperature is measured at center of any flat surface on the hexagonal head of the mounting stud.

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS		UNITS
		ALL TYPES		
		MIN.	MAX.	
* Reverse Current:				
Static				
For V_{RRM} = max. rated value, $I_F = 0$, $T_C = 25°C$	I_{RM}	–	50	µA
$T_C = 100°C$		–	6	mA
Dynamic				
For single phase full cycle average, $I_o = 20$ A, $T_C = 100°C$	$I_{R(AV)}$	–	10	mA
* Instantaneous Forward Voltage Drop:				
At $i_F = 20$ A, V_{RRM} = rated value, $T_J = 100°C$	$v_{F(PK)}$	–	1.5	V
At $i_F = 20$ A, $T_J = 25°C$	v_F	–	1.4	V
* Reverse Recovery Time:				
For circuit shown in Fig. 2, at				
$I_{FM} = 1$ A, $I_{RM} = 2$ A max., $T_C = 25°C$	t_{rr}	–	200	ns
Thermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	1.5	°C/W

*In accordance with JEDEC registration data.

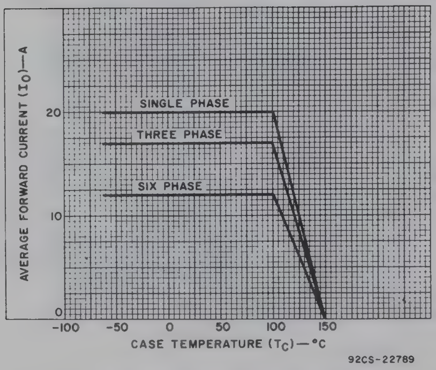


Fig. 1 — Average forward current vs. case temperature.

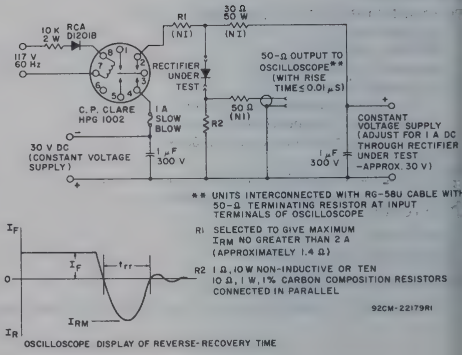

10 K
2 W
RCA
D1201B
117 V
60 Hz
C. P. CLARE
HPG 1002
R1
(NI)
30 Ω
50 W
(NI)
RECTIFIER
UNDER
TEST
50-Ω OUTPUT TO
OSCILLOSCOPE**
(WITH RISE
TIME≤0.01 µS)
50 Ω
(NI)
R2
1 A
SLOW
BLOW
30 V DC
(CONSTANT VOLTAGE
SUPPLY)
1 µF
300 V
1 µF
300 V
CONSTANT
VOLTAGE SUPPLY
(ADJUST FOR 1 A DC
THROUGH RECTIFIER
UNDER TEST
-APPROX. 30 V)
** UNITS INTERCONNECTED WITH RG-58U CABLE WIT
50-Ω TERMINATING RESISTOR AT INPUT
TERMINALS OF OSCILLOSCOPE
R1 SELECTED TO GIVE MAXIMUM
IRM NO GREATER THAN 2 A
(APPROXIMATELY 1.4 Ω)
R2 1 Ω, 10 W NON-INDUCTIVE OR TEN
10 Ω, 1 W, 1% CARBON COMPOSITION RESISTORS
CONNECTED IN PARALLEL
92CM-22179R1
IF
IF
0
trr
IRM
IR
OSCILLOSCOPE DISPLAY OF REVERSE-RECOVERY TIME

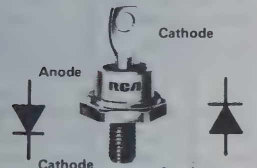
Fig. 2 Test circuit (pulsed dc) for measurement of reverse-recovery time.

RCA

Solid State
Division

Rectifiers

1N3909–1N3913
1N3909R–1N3913R



orward-polarity (N3909-1N3913)

Reverse-polarity (1N3909R-1N3913R)

JEDEC DO-5

H-1113R1

30-A, 50-to-400-V, Fast-Recovery Silicon Rectifiers

General-Purpose Types for High-Current Applications

Features:

- Available in reverse-polarity versions: 1N3909R, 1N3910R, 1N3911R, 1N3912R, 1N3913R
- Fast reverse-recovery time (t_{rr}) — 200 ns max. (I_{RM} = 1 A, I_{RM} = 2 A max., see test circuit Fig. 2)
- Low reverse-recovery current
- Low forward-voltage drop
- Low-thermal-resistance hermetic package

For data on other RCA fast recovery rectifiers, refer to the following RCA data bulletins:

6-A File No. 663 (D2406 Series)
12-A File No. 664 (D2412 Series)
20-A File No. 665 (D2520 Series)
40-A File No. 580 (D2540 Series)

CA types 1N3909 — 1N3913 and 1N3909R — 1N3913R are ffused-junction silicon rectifiers in a stud-type hermetic ckage. These devices differ only in their voltage ratings.

All types feature fast reverse-recovery time of 200 ns max. These devices are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications

AXIMUM RATINGS, *Absolute-Maximum Values:*		1N3909 1N3909R	1N3910 1N3910R	1N3911 1N3911R	1N3912 1N3912R	1N3913 1N3913R	
EVERSE VOLTAGE:							
Repetitive peak	V_{RRM}	50	100	200	300	400	V
Jon-repetitive peak	V_{RSM}	75	200	300	400	500	V
C (Blocking)	V_R	50	100	200	300	400	V
RWARD CURRENT (Conduction angle = 180°, half sine wave):							
RMS (T_C = 100°C)▲	$I_{F(RMS)}$	45					A
Average (T_C = 100°C)▲	I_o	30					A
Peak-surge (non-repetitive):	I_{FSM}						
At junction temperature (T_J) = 150°C:							
For one cycle of applied voltage, 60 Hz		300					A
For ten cycles of applied voltage, 60 Hz		160					A
Peak (repetitive)	I_{FRM}	125					A
TORAGE-TEMPERATURE RANGE	T_{stg}	−65 to 175					°C
PERATING (JUNCTION) TEMPERATURE	T_J	−65 to 150					°C
UD TORQUE:	τ_s						
ecommended		30					in-lb
Maximum (DO NOT EXCEED)		50					in-lb

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n accordance with JEDEC registration data.

ase temperature is measured at center of any flat surface on the hexagonal head of the mounting stud.

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS ALL TYPES MIN.	 MAX.	UNITS
* Reverse Current:				
Static				
For V_{RRM} = max. rated value, $I_F = 0$, $T_C = 25°C$	I_{RM}	–	80	μA
$T_C = 100°C$		–	10	mA
Dynamic				
For single phase full cycle average, $I_o = 30$ A, $T_C = 100°C$	$I_{R(AV)}$	–	15	mA
* Instantaneous Forward Voltage Drop:				
At $i_F = 30$ A, V_{RRM} = rated value, $T_J = 100°C$	$v_{F(PK)}$	–	1.5	V
At $i_F = 30$ A, $T_J = 25°C$	v_F	–	1.4	V
* Reverse Recovery Time:				
For circuit shown in Fig. 2, at $I_{FM} = 1$ A, $I_{RM} = 2$ A max., $T_C = 25°C$	t_{rr}	–	200	ns
Thermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	1	°C/W

*In accordance with JEDEC registration data.

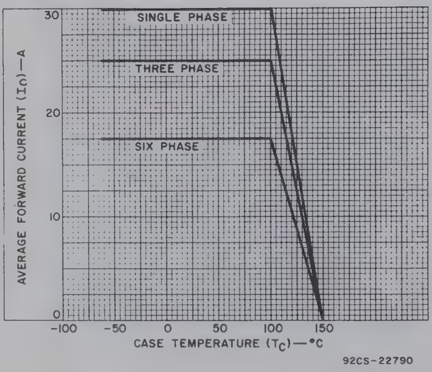


Fig. 1 — Average forward current vs. case temperature.

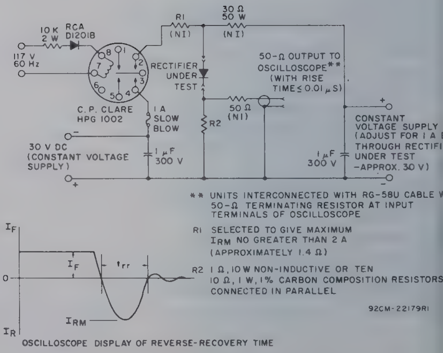

10 K
2 W
RCA
D1201B
117 V
60 Hz
1
2
3
4
5
6
7
8
C. P. CLARE
HPG 1002
R1
(N1)
30 Ω
50 W
(N1)
RECTIFIER
UNDER
TEST
50-Ω OUTPUT TO
OSCILLOSCOPE**
(WITH RISE
TIME ≤ 0.01 μS)
50 Ω
(N1)
R2
1 A
SLOW
BLOW
30 V DC
(CONSTANT VOLTAGE
SUPPLY)
1 μF
300 V
1 μF
300 V
CONSTANT
VOLTAGE SUPPLY
(ADJUST FOR 1 A
THROUGH RECTIFI
UNDER TEST
-APPROX. 30 V)
** UNITS INTERCONNECTED WITH RG-58U CABLE W
50-Ω TERMINATING RESISTOR AT INPUT
TERMINALS OF OSCILLOSCOPE
R1 SELECTED TO GIVE MAXIMUM
I_RM NO GREATER THAN 2 A
(APPROXIMATELY 1.4 Ω)
R2 1 Ω, 10 W NON-INDUCTIVE OR TEN
10 Ω, 1 W, 1% CARBON COMPOSITION RESISTORS
CONNECTED IN PARALLEL
92CM-22179R1
I_F
I_F
t_rr
0
I_RM
I_R
OSCILLOSCOPE DISPLAY OF REVERSE-RECOVERY TIME

Fig. 2 — Test circuit (pulsed dc) for measurement of reverse-recovery time.

RCA
Solid State Division

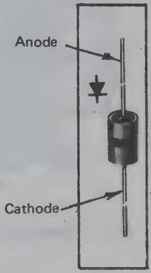
Rectifiers

1N5211 1N5212 1N5213 1N5214 1N5215 1N5216 1N5217 1N5218

SILICON RECTIFIERS

DIFFUSED-JUNCTION TYPES

For Industrial and Consumer-Product Applications



L-391
JEDEC DO-26

RCA-1N5211, 1N5212, 1N5213, 1N5214, 1N5215, N5216, 1N5217, and 1N5218* are hermetically sealed ilicon rectifiers of the diffused-junction type utilizing mall cylindrical metal cases and axial leads. Types N5215, 1N5216, 1N5217, and 1N5218 are insulated ersions of types 1N5211, 1N5212, 1N5213, and 1N5214, espectively. These rectifiers feature dc forward curent ratings of up to 1 A, a surge-current rating of 50A, ow forward voltage drop, low leakage currents, and an perating-temperature range of -65°C to +175°C.

- cylindrical design with axial leads for simple handling and installation
- compact, hermetically sealed metal case (0.405" max. length; 0.240" max. dia.)
- types 1N5215 through 1N5218 have transparent, high-dielectric-strength plastic sleeve over metal case
- high maximum forward-current ratings – up to 1 ampere DC at 75°C
- peak-reverse-voltage ratings from 200 to 800 volts
- operation at ambient temperatures to +175°C

RECTIFIER SERVICE (For a supply-line frequency of 60 Hz)

laximum Ratings, *Absolute-Maximum Values:*

	For resistive or inductive load				*For capacitor-input filter*					
	1N5211 1N5215	1N5212 1N5216	1N5213 1N5217	1N5214 1N5218	1N5211 1N5215	1N5212 1N5216	1N5213 1N5217	1N5214 1N5218		
EAK REVERSE VOLTAGE	200	400	600	800	200	400	600	800	max.	V
MS SUPPLY VOLTAGE	140	280	420	560	70	140	210	280	max.	V
ORWARD CURRENT: For ambient temperatures up to 75°C. For ambient temperatures above 75°C, see Rating Chart.										
DC	1	1	1	0.75	0.75	0.75	0.75	0.6	max.	A
PEAK RECURRENT	-	-	-	-	6	6	6	5	max.	A
SURGE — For "turn-on" time of 2 milliseconds	-	-	-	-	50	50	50	50	max.	A
MBIENT-TEMPERATURE RANGE:										
Operating	-65 to +175									°C
Storage	-65 to +175									°C
EAD TEMPERATURE:										
For 10 seconds maximum	255								max.	°C

haracteristics:

	1N5211 1N5215	1N5212 1N5216	1N5213 1N5217	1N5214 1N5218		
aximum Instantaneous Forward Voltage Drop at dc forward current of 1 ampere and $T_A \leq 75^{\circ}C$	1.2	1.2	1.2	1.2	max.	V
laximum Reverse Current:						
Dynamic, at $T_A = 75^{\circ}C$**	0.2	0.2	0.2	0.2	max.	mA
Static, at $T_A = 25^{\circ}C$***	0.005	0.005	0.005	0.005	max.	mA

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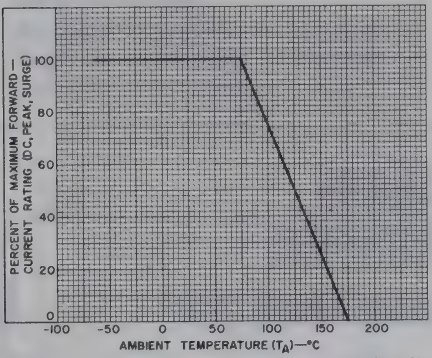
* Formerly Dev. Nos. TA2845C, TA2845B, TA2845A, TA2845, TA7048C, TA7048B, TA7048A, and TA7048, respectively.

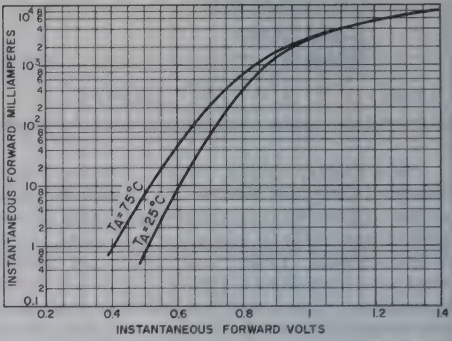
*At max. peak reverse voltage and max. dc forward current.

***At max. peak reverse voltage and zero forward current.



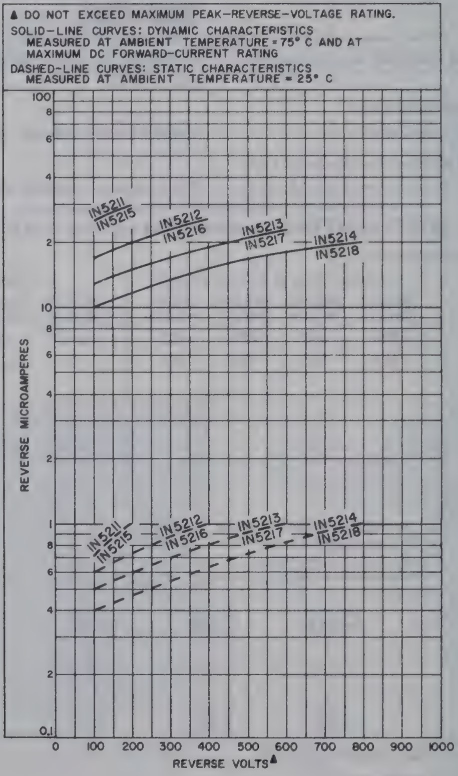
92CS-14455

Fig.1 - Rating Chart for Types 1N5211 through 1N5218.



92CS-14467

Fig.2 - Typical Forward Characteristics for Types 1N5211 through 1N5218.


▲ DO NOT EXCEED MAXIMUM PEAK-REVERSE-VOLTAGE RATING.

SOLID-LINE CURVES: DYNAMIC CHARACTERISTICS MEASURED AT AMBIENT TEMPERATURE = 75° C AND AT MAXIMUM DC FORWARD-CURRENT RATING

DASHED-LINE CURVES: STATIC CHARACTERISTICS MEASURED AT AMBIENT TEMPERATURE = 25° C

92CM-14458

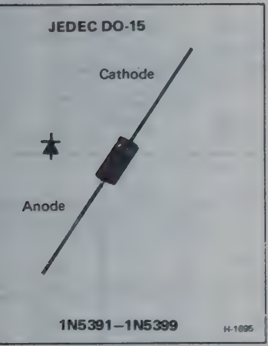
Fig.3 - Typical Reverse Characteristics for Types 1N5211 through 1N5218.

RCA

Solid State
Division

Rectifiers

1N5391--1N5399



1.5-A, 50–1000-V Silicon Rectifiers

Plastic-Packaged, General-Purpose Types for Low-Power Applications

Features:

- **High surge-current capability**
- **Low junction-to-lead thermal impedances**
- **–65 to +170° operating temperature range**

A-1N5391--1N5399, inclusive, are diffused-junction type con rectifiers in an axial-lead plastic package. These de- es differ only in their voltage ratings.

Their small size and plastic package of high insulation resistance make these rectifiers especially suitable for those applications in which high packaging densities are employed.

XIMUM RATINGS, *Absolute-Maximum Values:*

VERSE VOLTAGE:		1N5391	1N5392	1N5393	1N5394	1N5395	1N5396	1N5397	1N5398	1N5399	
REPETITIVE PEAK■	V_{RRM}	50	100	200	300	400	500	600	800	1000	V
NON-REPETITIVE PEAK▼	V_{RSM}	100	200	300	400	525	650	800	1000	1200	V
WORKING PEAK▲	V_{RWM}	50	100	200	300	400	500	600	800	1000	V
DC BLOCKING (At T_A = 150°C)	V_R	50	100	200	300	400	500	600	800	1000	V
RMS	$V_{R(RMS)}$	35	70	140	210	280	350	420	560	700	V

RWARD CURRENT:		All Types	
AVERAGE RECTIFIED	I_o	1.5	A
Single-phase, half-wave operation with 60-Hz sinusoidal voltage and resistive load, and 1/2-inch leads; for other lead lengths, see Fig. 1. T_A = 70°C			
PEAK SURGE	I_{FSM}		
For one-half cycle of applied voltage, 50 Hz (10 ms)		45	A
*60 Hz (8.3 ms)		50	A
400 Hz (1.25 ms), T_A = 70°C		100	A
For other durations		See Fig. 4.	
MPERATURE RANGE:			
Storage		–65 to +175	°C
Operating		–65 to +170	°C
AD TEMPERATURE (During Soldering):			
Measured 1/8 inch from case for 10 s max.		240	°C

For single-phase, half-wave sinusoidal pulse of 100-μs duration with a repetition rate of 60 pulses per second.

For one single-phase, half-wave, 60-Hz sinusoidal pulse with this peak value.

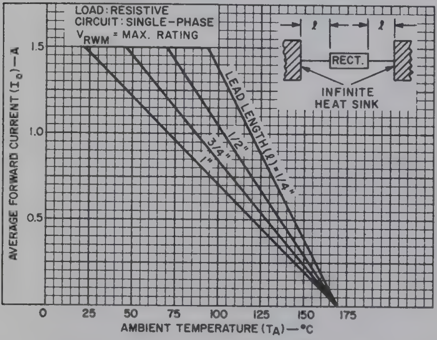
Maximum input-voltage rating that can be continuously applied (with the maximum current rating) over the normal operating temperature range|. For single-phase, half-wave operation with a 60-Hz sinusoidal supply and a resistive load.

In accordance with JEDEC registration format JS-1 RDF-3.

ELECTRICAL CHARACTERISTICS

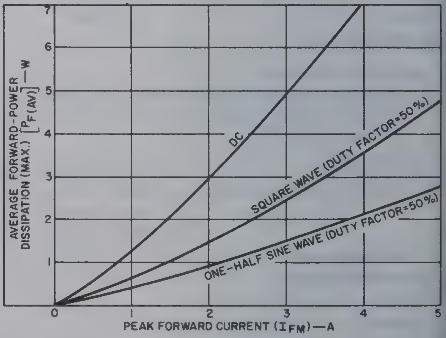
CHARACTERISTIC	SYMBOL	LIMITS			UNITS
		All Types			
		Min.	Typ.	Max.	
Reverse Current:					
**Static*					
For V_R = rated value & T_J = 25°C	I_R	–	0.001	0.01*	mA
For V_R = rated value & T_J = 150°C		–	0.100	0.3*	
**Dynamic* Full-cycle average, for V_{RWM} = rated value, I_o = 1.5A, T_A = 70°C	$I_{R(AV)}$	–	0.080	0.3*	mA
***Instantaneous Forward-Voltage Drop:** At i_F = 1.5A, T_A = 70°C, see Fig. 3.	v_F	–	1.1	1.4*	V
Reverse-Recovery Time: At I_{FM} = 30A, pulse duration = 3.1 μs, T_A = 25°C (See Fig. 7; for other conditions, see Fig. 8.)	t_{rr}	–	1.5	–	μs
***Thermal Impedance:**					
Steady-State					
Junction-to-anode-lead	$\theta_{J\text{-}L_a}$	–	–	100	°C/W
Junction-to-cathode-lead	$\theta_{J\text{-}L_k}$	–	–	100	
Anode-Lead } Free convection cooling	–	–	–	148	°C/W/in
Cathode-Lead } Free convection cooling	–	–	–	148	
Transient Heat-sink mounting with 0-to-1¼" leads, and with a pulse duration of 0.6 s. For other pulse durations, see Fig. 6.	$\theta_{J\text{-}HS(t)}$	–	10	–	°C/W

* In accordance with JEDEC registration data format JS-1 RDF-3



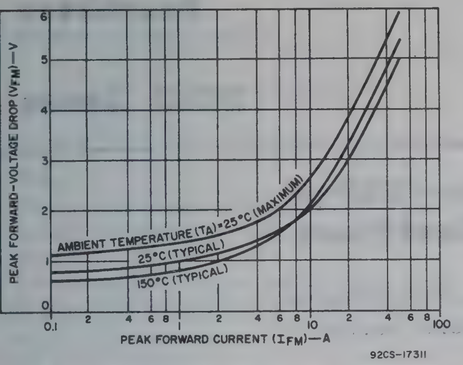
92CS–17312

Fig. 1 - Average-forward-current derating curves for types 1N5391–1N5399 for several lead lengths.



92CS–17305

Fig. 2 - Variation of peak forward-power dissipation wit peak forward current.



ig. 3 - Peak forward-voltage drop vs. peak forward current or types 1N5391–1N5399.

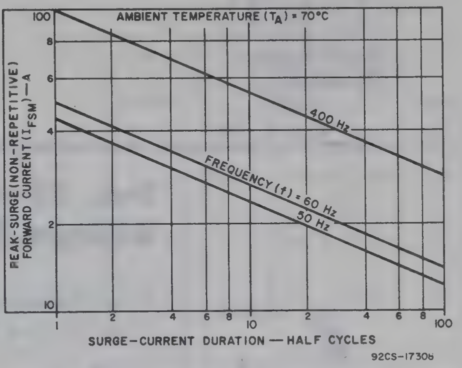
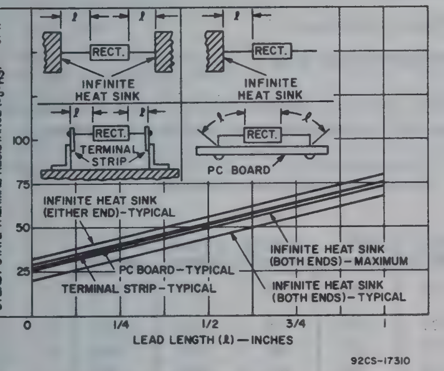


Fig. 4 - Peak-surge (non-repetitive) forward current vs. surge-current duration for types 1N5391–1N5399.



g. 5 - Variation of steady-state thermal resistance with lead ngth (for different mounting methods) for types 1N5391-- I5399.

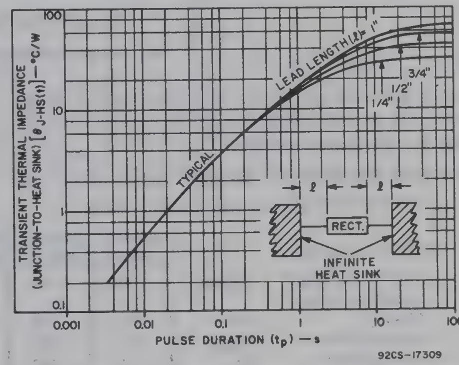
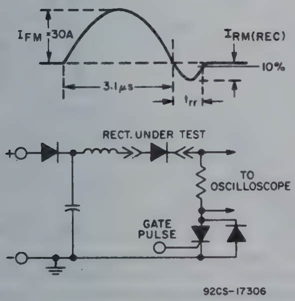


Fig. 6 - Variation of transient thermal impedance with pulse duration for several lead lengths for types 1N5391--1N5399.


IFM =30A
IRM(REC)
10%
3.1µs
trr
RECT. UNDER TEST
TO OSCILLOSCOPE
GATE PULSE
+
-
92CS-17306

g. 7 - Oscilloscope display & test circuit for measurement reverse-recovery time.

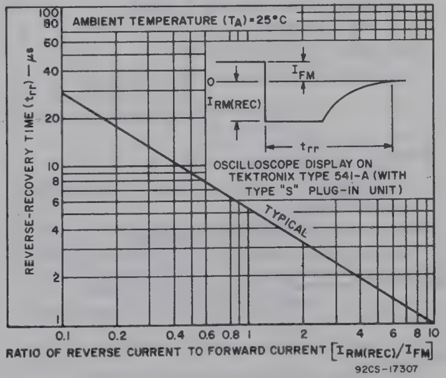


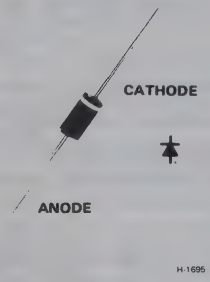
Fig. 8 - Variation of reverse-recovery time with ratio of reverse-to-forward current for types 1N5391--1N5399.

RCA

Solid State Division

Rectifiers

D1201 Series



1-A, 50-to-1000-V Silicon Rectifiers

Plastic-Packaged, General-Purpose Types for Low-Power Applications

Features:

- **Electrically identical to JEDEC types 1N4001–1N4007**
- **High surge-current capability**
- **Low junction-to-lead thermal impedances**
- **–65 to +175°C operating temperature range**

RCA D1201 series† devices are diffused-junction type silicon rectifiers in an axial-lead plastic package. These devices differ only in their voltage ratings.

Their small size and plastic package of high insulation resistance make these rectifiers especially suited for those applications in which high packing densities are desirable.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

REVERSE VOLTAGE:		D1201F (44001)*	D1201A (44002)*	D1201B (44003)*	D1201D (44004)*	D1201M (44005)*	D1201N (44006)*	D1201P (44007)*	
REPETITIVE PEAK♠	V_{RRM}	50	100	200	400	600	800	1000	V
NON-REPETITIVE PEAK♦	V_{RSM}	100	150	300	525	800	1000	1200	V
WORKING PEAK▲	V_{RWM}	50	100	200	400	600	800	1000	V
DC BLOCKING	V_R	50	100	200	400	600	800	1000	V
RMS	$V_{R(RMS)}$	35	70	140	280	420	560	700	V

		All Types	
FORWARD CURRENT:			
AVERAGE-RECTIFIED:	I_o		A
Single-phase, half-wave operation with 60-Hz sinusoidal voltage and resistive load; with 1″ leads. $T_A = 75°C$		1	
For other lead lengths		See Fig. 1	
PEAK-SURGE (NON-REPETITIVE):	I_{FSM}		
For one-half cycle of applied voltage, 50 Hz (10 ms)		28	A
60 Hz (8.3 ms)		30	A
400 Hz (1.25 ms)		60	A
For other durations		See Fig. 3	
TEMPERATURE RANGE:			
With 1-inch leads & infinite-heat-sink mounting (both leads):			
Storage & Operating		–65 to 175	°C
LEAD TEMPERATURE (During Soldering):	T_L		
Measured 3/8 in. (9.52 mm) from case for 10 s max.■		350	°C

---

† Types D1201A, B, C, D, M, and N were formerly RCA Dev. Nos. TA7996 and TA7802-TA7806, respectively.

* Number in parentheses is a former RCA type number.

♠ For single-phase, half-wave sinusoidal pulse of 100–μs duration and a repetition rate of 60 pulses per second.

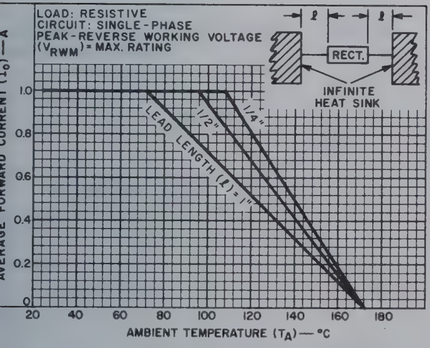
♦ For one single-phase, half-wave, 60-Hz sinusoidal pulse with this peak value.

▲ Maximum input voltage that can be continuously applied (with the maximum current rating) over the normal operating-temperature range. For single-phase, half-wave operation with a 60-Hz sinusoidal supply and a resistive load.

■ Measured on anode or cathode lead.

LECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS All Types Min.	Typ.	Max.	UNITS
everse Current:					
Static					
For V_R = rated value & T_J = 25°C	I_R	–	–	0.01	mA
For V_R = rated value & T_J = 100°C		–	–	0.05	
Dynamic					
Full-cycle average, for V_{RWM} = rated value, I_o = 1 A, T_A = 75°C	$I_{R(AV)}$	–	–	0.03	mA
stantaneous Forward-Voltage Drop:					
At i_F = 1 A, T_J = 25°C, see Fig. 2	v_F	–	0.95	1.1	V
everse-Recovery Time:					
At I_{FSM} = 30 A, pulse duration = 3.1 µs, T_A = 25°C, see Fig. 6	t_{rr}	–	1.5	–	µs
For other conditions			See Fig. 7		
ermal Impedance (Junction-to-Heat Sink):					
Steady-State					
Heat-sink mounting with 1-inch leads. For other mounting methods and other lead lengths, see Fig. 4	$\theta_{J\text{-}HS(t)}$	–	50	55	°C/W
Transient					
Heat-sink mounting with 0 to 1″ leads, and with a pulse duration of 0.3 s. For other pulse durations, see Fig. 5	$\theta_{J\text{-}HS(t)}$	–	7.5	–	°C/W



1—*Average-forward-current derating curves for several lead lengths.*

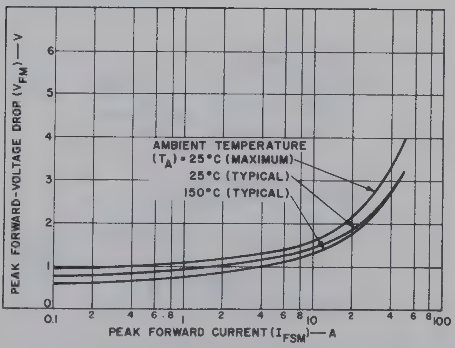


Fig. 2—Peak forward-voltage drop vs. peak forward current.

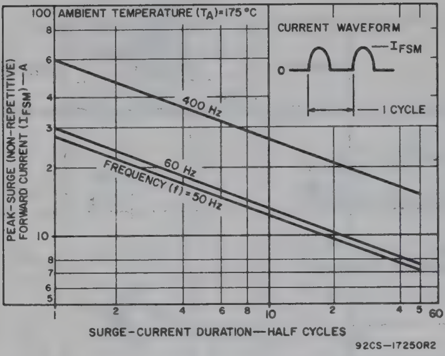


Fig. 3—Peak-surge (non-repetitive) forward current vs. surge-current duration.

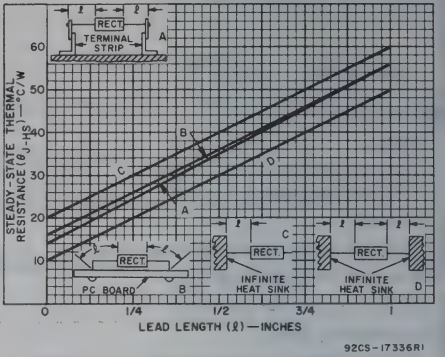


Fig. 4—Typical steady-state thermal resistance with lead length (for different mounting methods).

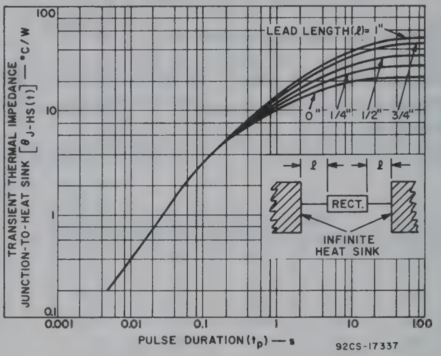


Fig. 5—Typical variation of transient thermal impedance with pulse duration for several lead lengths.

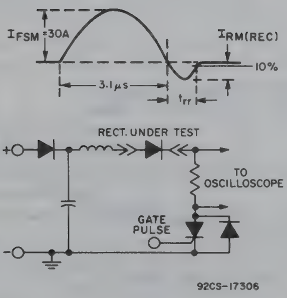

I_FSM =30A
I_RM(REC)
10%
3.1 μs
t_rr
RECT. UNDER TEST
+
TO OSCILLOSCOPE
GATE PULSE
-
92CS-17306

Fig. 6—Oscilloscope display and test circuit for measurement of reverse-recovery time.

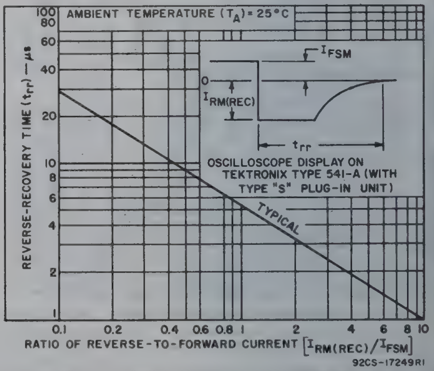
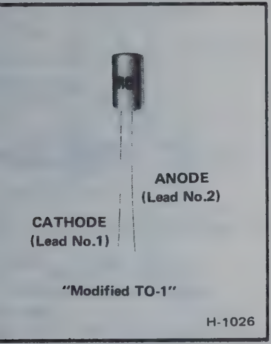


Fig. 7—Typical reverse-recovery time with ratio of reverse-to-forward current.

Solid State
Division

Rectifiers

D1300 Series



0.25-A, 100-to-400-V Silicon Rectifiers

General-Purpose Types for Low-Power Applications

Features:

- Hermetically sealed metal case, leads insulated from case — modified TO-1
- Operation at ambient temperatures to 125°C
- Single-ended for ease of handling and installation

Voltage / Package	100 V	200 V	400 V
"Modified TO-1"	D1300A	D1300B	D1300D

CA D1300-series devices are diffused-junction silicon rec-iers in a hermetically sealed ("modified TO-1") 2-lead se. These devices differ from each other in their volt-e ratings.

The D1300-series types are intended for use in amplifiers as compensating diodes (temperature and voltage), low-current bridge circuits, and other low-power service in industrial, consumer-product, and military applications.

AXIMUM RATINGS, *Absolute-Maximum Values:*

		D1300A	D1300B	D1300D	
EVERSE VOLTAGE:					
Repetitive Peak♣	V_{RRM}	100	200	400	V
Non-Repetitive Peak♦	V_{RSM}	150	300	525	V
Working Peak▲	V_{RWM}	100	200	400	V
DC Blocking	V_R	100	200	400	V
RMS	$V_{R(RMS)}$	70	140	280	V
ORWARD CURRENT:					
Average Rectified ($T_A = 65^{o}C$):	I_o				
Single-phase, half-wave operation with 60-Hz sinusoidal voltage and resistive load			0.25		A
For other temperatures			See Fig. 1		
Peak Surge (Non-Repetitive) ($T_A = 125^{o}C$):	I_{FSM}				
For one-half cycle of applied voltage, 50 Hz (10 ms)			28		A
60 Hz (8.3 ms)			30		A
400 Hz (1.25 ms)			60		A
For other durations			See Fig. 2		
EMPERATURE RANGE:					
Storage	T_{stg}		−65 to 175		°C
Operating	$T_{oper.}$		−65 to 125		°C
EAD TEMPERATURE (During Soldering):					
Measured 3/8 in. (9.52 mm) from case for 10 s max.	T_L		255		°C

For single-phase, half-wave sinusoidal pulse of 100-µs duration and a repetition rate of 60 pulses per second.

For one single-phase, half wave, 60-Hz sinusoidal pulse with this peak value.

▲ Maximum input voltage that can be continuously applied (with the maximum current rating) over the normal operating temperature range. For single-phase half-wave operation with a 60-Hz sinusoidal supply and a resistive load.

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS All Types Min.	 Typ.	 Max.	UNITS
Reverse Current: *Static*					
For V_R = rated value & T_J = 25°C	I_R	–	–	0.01	mA
For V_R = rated value & T_J = 125°C		–	–	0.1	
Dynamic Full-cycle average, for V_{RWM} = rated value, I_o = 0.25 A, T_A = 65°C	$I_{R(AV)}$	–	–	0.06	mA
Instantaneous Forward-Voltage Drop: At i_F = 0.25 A, T_A = 25°C (See Fig.4)	v_F	–	0.88	1	V
Reverse-Recovery Time: At I_{FSM} = 20 mA, I_{RM} = 2 mA, T_A = 25°C	t_{rr}	–	30	–	μs
For other conditions			See Fig. 3		
Thermal Impedance (Junction-to-Air): *Steady-State*	$\theta_{J\text{-}A}$	–	–	250	°C/W

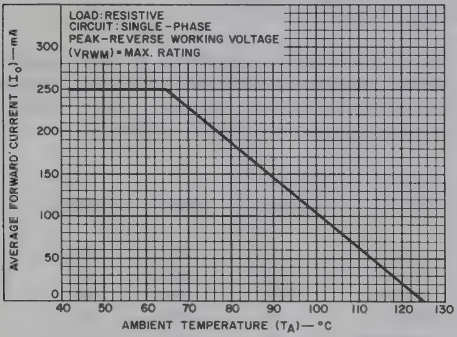


Fig.1 – Average-forward-current derating curve.

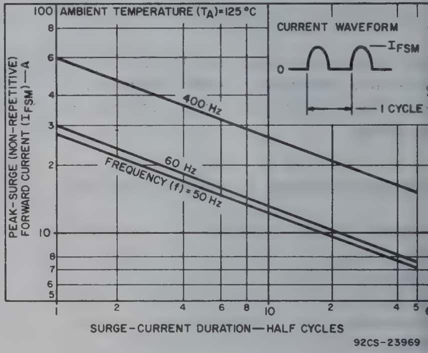


Fig.2 – Peak-surge (non-repetitive) forward current vs. surge-curre duration.

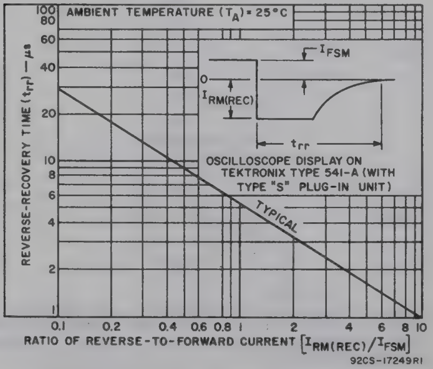


Fig.3 – Typical reverse-recovery time vs. ratio of reverse-to-forward current.

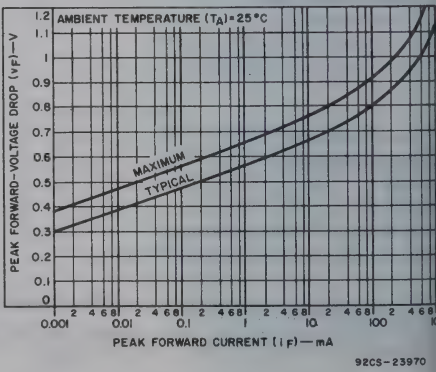
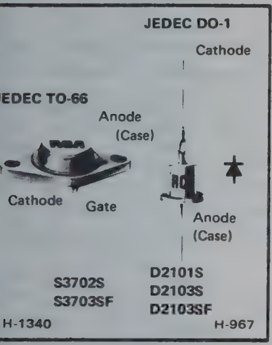


Fig.4 – Peak forward voltage drop vs. peak forward current.

RCA
Solid State Division

Thyristors/Rectifiers
S3702S D2101S
S3703SF D2103S
D2103SF


JEDEC DO-1
Cathode
EDEC TO-66
Anode
(Case)
Cathode
Gate
Anode
(Case)
S3702S
S3703SF
D2101S
D2103S
D2103SF
H-1340
H-967

SCR's and Rectifiers for Horizontal-Deflection Circuits

For 110° Large-Screen Color TV

Features:

- Operation from supply voltages between 150 and 270 V (nominal)
- Ability to handle high beam current; average 1.6 mA dc
- Ability to supply as much as 8 mJ of stored energy to the deflection yoke, which is sufficient for 29-mm-neck and 36.5-mm-neck picture tubes operated at 31 kV (nominal value)
- Highly reliable circuit which can also be used as a low-voltage power supply

Voltage / Package	700 V Types	750 V Types
TO-66	S3702S (40889)	S3703SF (40888)
DO-1	D2101S D2103S (40892) (40891)	D2103SF (40890)

Numbers in parentheses are former RCA type numbers.

ese RCA types are designed for use in a horizontal output cuit such as that shown in Fig. 1.

e S3703SF silicon controlled rectifier and the D2103SF con rectifier are designed to act as a bipolar switch that ntrols horizontal yoke current during the beam trace interval. e S3702S silicon controlled rectifier and the D2103S silicon ctifier act as the commutating switch to initiate trace-retrace itching and control yoke current during retrace.

The D2101S silicon rectifier may be used as a clamp to protect the circuit components from excessively high transient voltages which may be generated as a result of arcing in the picture tube or in a high-voltage rectifier tube.

To facilitate direct connection across each silicon controlled rectifier, S3702S and S3703SF, the anode connections of silicon rectifiers D2103S and D2103SF are reversed as compared to that of a normal power-supply rectifier diode.

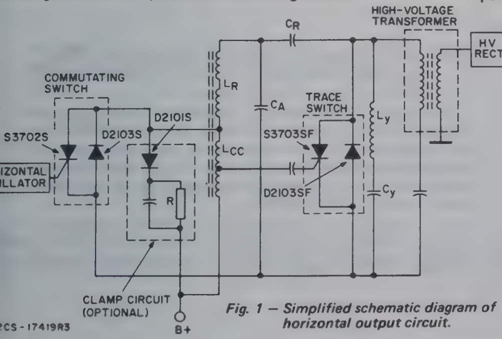

HIGH-VOLTAGE TRANSFORMER
CR
HV RECT.
TO PICTURE TUBE
COMMUTATING SWITCH
LR
CA
TRACE SWITCH
Ly
D2101S
S3702S
D2103S
S3703SF
LCC
IZONTAL ILLATOR
R
D2103SF
Cy
CLAMP CIRCUIT (OPTIONAL)
B+
CS-17419R3

Fig. 1 — Simplified schematic diagram of horizontal output circuit.

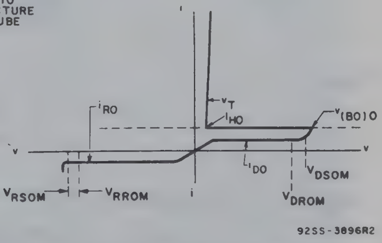


Fig. 2 — Principal voltage-current characteristic for S3702S and S3703SF.

SILICON CONTROLLED RECTIFIERS

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		S3703SF TRACE SCR	S3702S COMMUTATING SCR	
NON-REPETITIVE PEAK OFF-STATE VOLTAGE:•				
Gate Open	V_{DSOM}	800*	750*	V
REPETITIVE PEAK REVERSE VOLTAGE:•				
Gate Open	V_{RROM}	25	25	V
REPETITIVE PEAK OFF-STATE VOLTAGE:•				
Gate Open	V_{DROM}	750	700	V
ON-STATE CURRENT:				
T_C = 60°C, 50 Hz sine wave, conduction angle = 180°:				
RMS	$I_{T(RMS)}$	5	5	A
Average DC	$I_{T(AV)}$	3.2	3.2	A
PEAK SURGE (NON–REPETITIVE) ON-STATE CURRENT:	I_{TSM}			
For one full cycle of applied principal voltage 50 Hz (sinusoidal), T_C = 60°C		65	65	A
For one-half sine wave, 3 ms pulse width		130	130	A
RATE OF CHANGE OF ON-STATE CURRENT:				
$V_D = V_{DROM}$, I_{GT} = 50 mA, t_r = 0.1 μs	di/dt	200	200	A/μs
FUSING CURRENT (for SCR protection):				
T_J = −40 to 80°C, t = 1 to 10 ms	I^2t	20	20	A^2s
GATE POWER DISSIPATION:■	P_{GM}			
Peak (forward or reverse) for 10 μs duration, max. negative gate bias = −35 V (S3703SF)		25	–	W
= −10 V (S3702S)		–	25	W
TEMPERATURE RANGE:▲				
Storage	T_{stg}	−40 to 150	−40 to 150	°C
Operating (Case)	T_C	−40 to 80	−40 to 80	°C
PIN TEMPERATURE (During soldering):				
At distances ≥ 1/32 in. (0.8 mm) from seating plane for 10 s max.	T_P	225	225	°C

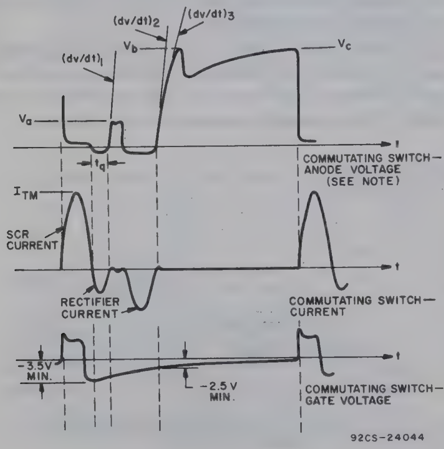
---

*Protection against transients induced by arcing or other causes must be provided.

•These values do not apply if there is a positive gate signal. Gate must be open or negatively biased.

■Any product of gate current and gate voltage which results in a gate power less than the maximum is permitted, provided that the maximum reverse gate bias (as specified) is not exceeded.

▲For temperature measurement reference point, see Dimensional Outline.


(dv/dt)2
(dv/dt)3
Vb
Vc
(dv/dt)1
Va
tq
COMMUTATING SWITCH—ANODE VOLTAGE (SEE NOTE)
ITM
SCR CURRENT
RECTIFIER CURRENT
COMMUTATING SWITCH—CURRENT
t
−3.5V MIN.
−2.5 V MIN.
COMMUTATING SWITCH—GATE VOLTAGE
92CS-24044

NOTE: "Commutating Switch-Anode Voltage" oscilloscope display has been modified graphically to enhance the measurement points of dv/dt.

I_{TM} = 15 A, V_a = 180 V max., V_b = 500 V max., $V_c = V_{DROM}$. Gate voltage = 12 V positive from 15 V supply. Gate current should rise to 100 mA within 0.2 μs. Minimum duration of gate current pulse = 3 μs. Minimum amplitude of gate current pulse = 200 mA. Negative gate bias at turn-off = −3.5 V minimum, negative gate bias at 2nd reapplied voltage $(dv/dt)_2$ = −2.5 V minimum.

$(dv/dt)_1$ = 400 V/μs (measured tangent to waveform from 0 to 0.8 of V_a)
$(dv/dt)_2$ = 1000 V/μs (measured tangent to waveform from 0 to 0.3 of V
$(dv/dt)_3$ = 700 V/μs (measured tangent to waveform from 0 to 0.8 of V_b

Fig. 3 – Oscilloscope display of commutating switching (S3702S) showing circuit-commutated turn-off time (tq).

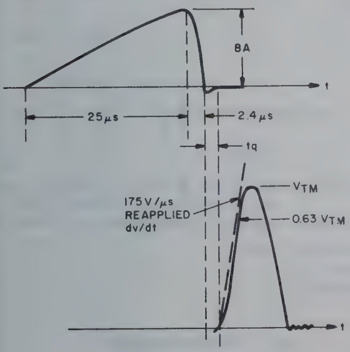
SILICON CONTROLLED RECTIFIERS

ELECTRICAL CHARACTERISTICS

At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS				UNITS
		S3703SF TRACE SCR		S3702S COMMUTATING SCR		
		TYP.	MAX.	TYP.	MAX.	
Peak Forward Off-State Current: Gate open, $V_D = V_{DROM}$ $T_C = 85°C$ . .	I_{DOM}	0.5	1.5	0.5	1.5	mA
Instantaneous On-State Voltage: $i_T = 30$ A (peak), $T_C = 25°C$	v_T	2.2	3	2.2	3	V
Critical Rate of Rise of Off-State Voltage: $V_D = V_{DROM}$, exponential voltage rise, Gate open, $T_C = 70°C$ (See Fig.3)	dv/dt	–	–	700 (min.) $(dv/dt)_3$		V/μs
DC Gate Trigger Current: $V_D = 12$ V (dc), $R_L = 30\ \Omega$, $T_C = 25°C$	I_{GT}	15	32	15	45	mA
DC Gate Trigger Voltage: $V_D = 12$ V (dc), $R_L = 30\ \Omega$, $T_C = 25°C$	V_{GT}	1.8	4	1.8	4	V
Circuit Commutated Turn-Off Time:◆ $T_C = 70°C$, minimum negative gate bias during turn-off time = –20 V (S3703SF) and –2.5 V (S3702S), rate of reapplied voltage (dv/dt) = 175 V/μs (See Fig. 4) . . . . = 400 V/μs (See Fig. 3	t_q	– –	2.4 –	– –	– 4.2	μs μs
Thermal Resistance, Junction-to-Case . . .	$R_{\theta JC}$	–	4	–	4	°C/W

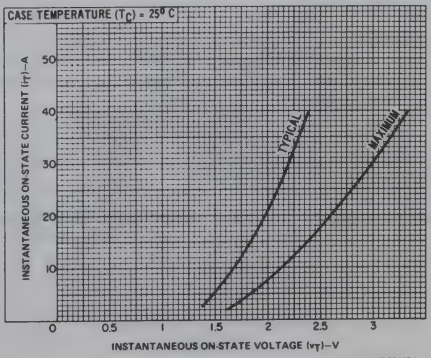
◆This parameter, the sum of reverse recovery time and gate recovery time, is measured from the zero crossing of current to the start of the reapplied voltage. Knowledge of the current, the reapplied voltage, and the case temperature is necessary when measuring t_q. In the worst conditions (high line, zero-beam, off-frequency, minimum auxiliary load, etc.), turn-off time must not fall below the given values. Turn-off time increases with temperature; therefore, case temperature must not exceed 70°C. See Figs. 3 and 4.



M = 8 A, $V_{TM} = V_{DROM}$, reapplied dv/dt = 175 V/μs (measured om 0 to 0.63 of V_{TM}), negative gate voltage source = –24 V, source pedance = 15 Ω.

92CS-24045

4 — Oscilloscope display of trace switching (S3703SF) showing circuit-commutating turn-off time (tq).



92LS-2344R1

Fig. 5 — Instantaneous on-state current vs. on-state voltage for S3702S and S3703SF.

SILICON RECTIFIERS

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		D2103SF TRACE	D2103S COMMUTATING	D2101S CLAMP	
REVERSE VOLTAGE:**					
Repetitive Peak	V_{RRM}	750	700	700	V
Non-Repetitive Peak●●	V_{RSM}	800	800	800	V
FORWARD CURRENT (operating in 15 kHz deflection circuit):					
RMS	$I_{F(RMS)}$	3■■	3■■	1**	A
Peak Surge (Non-Repetitive)●●	I_{FSM}	70◆◆	70◆◆	30◆◆	A
Peak (Repetitive)	I_{FRM}	7	12	0.5	A
TEMPERATURE RANGE					
Storage	T_{stg}		−30 to 150		°C
Operating (Case)	T_C		−30 to 80		°C
LEAD TEMPERATURE (During Soldering):▲▲					
For 10 s maximum	T_L		225		°C

** For ambient temperatures up to 45°C.

●● For a maximum of 3 pulses, each less than 10 μs duration, during any 64-μs period.

■■ Maximum current rating applies only if the rectifier is properly mounted to maintain junction temperature below 150°C. See Fig.15 and Fig.1

▲▲ At distances no closer to rectifier body than points A and B on outline drawing.

◆◆ See Fig. 9 for I_{FSM} value for 60 Hz.

SILICON RECTIFIERS

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS		UNITS
		D2103SF TRACE D2103S COMMUT.	D2101S CLAMP	
		MAXIMUM	MAXIMUM	
Reverse Current: *Static* For V_{RRM} = max. rated value, $I_F = 0$, $T_C = 25°C$ For $V_R = 500$ V, $T_C = 100°C$	I_{RM}	10 250	10 250	μA
Instantaneous Forward Voltage Drop: At $i_F = 4$ A, $T_A = 25°C$	v_F	1.4	1.5	V
Reverse Recovery Time: For circuit shown in Fig. 8: At $I_{FM} = 3.14$ A, $-di_F/dt = -10$ A/μs, pulse duration = 0.94 μs, $T_C = 25°C$	t_{rr}	0.5	0.7	μs
In Tektronix type "S" plug-in unit (or equivalent): At $I_F = 20$ mA, $I_R = 1$ mA $T_C = 25°C$		1	1.5	
Peak Forward Voltage Drop (at turn-on): In Tektronic type "S" plug-in unit (or equivalent): At $I_F = 20$ mA, $T_C = 25°C$	$V_{F(pk)}$	5	6	V
Thermal Resistance (Junction-to-Case)◆	$R_{\theta JC}$	10	10	°C/W

◆ Measured at point as indicated on Dimensional Outline.

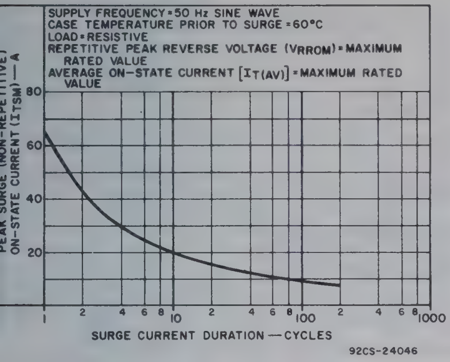


Fig. 6 – Peak surge on-state current vs. surge current duration for S3702S and S3703SF.

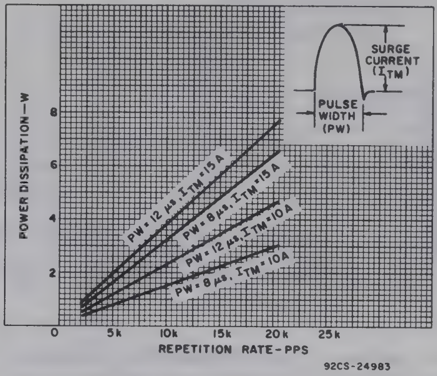
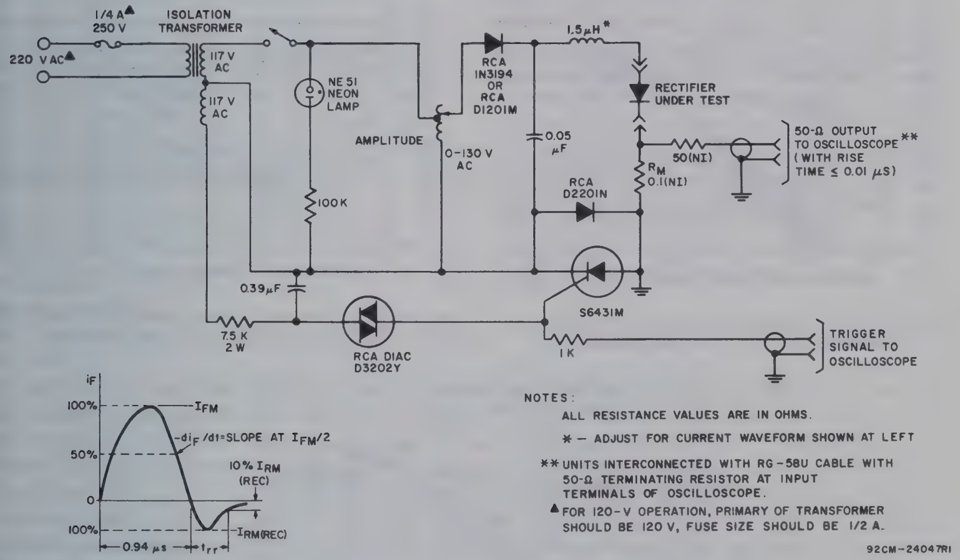


Fig. 7—Dissipation vs. repetition rate for S3702S and S3703SF


1/4 A▲
250 V
ISOLATION TRANSFORMER
220 V AC▲
117 V AC
117 V AC
NE 51 NEON LAMP
AMPLITUDE
0-130 V AC
100 K
RCA 1N3194 OR RCA D1201M
1.5 μH*
RECTIFIER UNDER TEST
0.05 μF
RCA D2201N
50 (NI)
RM 0.1 (NI)
50-Ω OUTPUT TO OSCILLOSCOPE** (WITH RISE TIME ≤ 0.01 μS)
0.39 μF
7.5 K 2 W
RCA DIAC D3202Y
S6431M
1 K
TRIGGER SIGNAL TO OSCILLOSCOPE
iF
100%
50%
0
100%
IFM
-diF/dt=SLOPE AT IFM/2
10% IRM (REC)
IRM(REC)
0.94 μs
trr
92CM-24047R1

NOTES:

ALL RESISTANCE VALUES ARE IN OHMS.

* – ADJUST FOR CURRENT WAVEFORM SHOWN AT LEFT

** UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE.

▲ FOR 120-V OPERATION, PRIMARY OF TRANSFORMER SHOULD BE 120 V, FUSE SIZE SHOULD BE 1/2 A.

Fig. 8 – Oscilloscope display and test circuit for measurement of reverse-recovery time for D2101S, D2103S, and D2103SF.

TERMINAL CONNECTIONS FOR TYPES S3702S AND S3703SF

Pin 1 – Gate
Pin 2 – Cathode
Case, Mounting Flange – Anode

TERMINAL CONNECTIONS FOR TYPES D2101S, D2103S, AND D2103SF

Case, Lead No. 1 – Anode
Lead No. 2 – Cathode

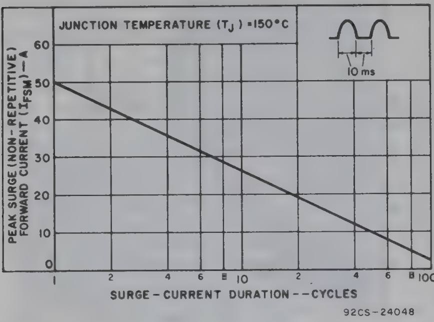


Fig. 9 – Peak surge (non-repetitive) forward current vs. surge-current duration for D2101S, D2103S, and D2103SF.

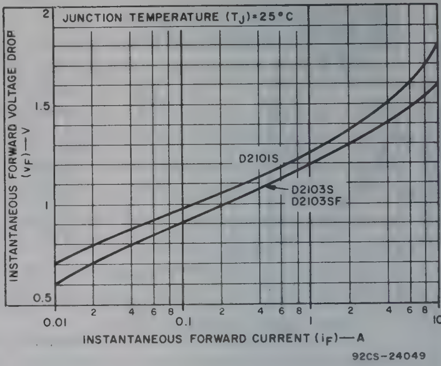


Fig. 10 – Forward-voltage drop vs. forward current for D2101S, D2103S, and D2103SF.

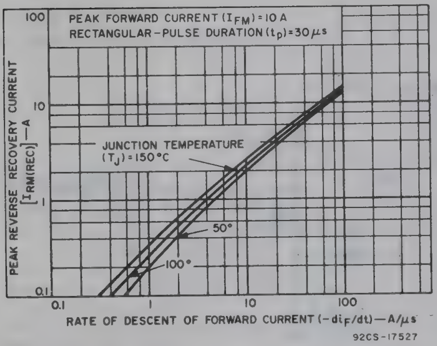


Fig. 11–Typical peak reverse recovery current vs. rate of descent of forward current for D2101S, D2103S, and D2103SF.

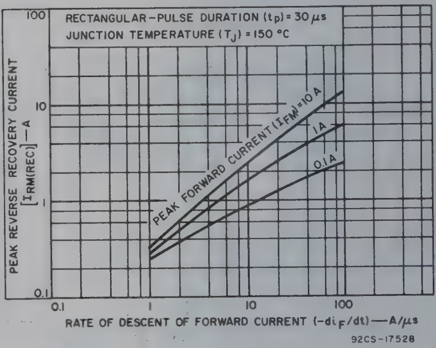


Fig. 12–Typical peak reverse recovery current vs. rate of descent of forward current for D2101S, D2103S, and D2103SF.

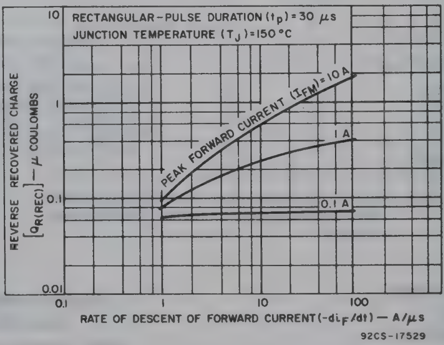
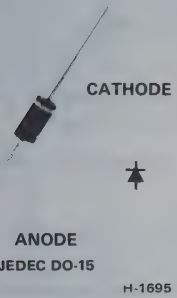


Fig. 13–Typical reverse recovered charge vs. rate of descent of forward current for D2101S, D2103S, and D2103SF.

Solid State
Division

Rectifiers

D2201 Series



1-A, 50-to-800-V Fast-Recovery Silicon Rectifiers

General-Purpose Types for Medium-Current Applications

Features:

- Fast turn-off: 0.5 µs max. from 3.14-A peak
- Low overshoot current
- Low forward voltage drop

Voltage / Package	50 V Type	100 V Type	200 V Type	400 V Type	600 V Type	800 V Type
DO-15	D2201F (44933)	D2201A (44934)	D2201B (44935)	D2201D (44936)	D2201M (44937)	D2201N (44938)

Numbers in parentheses are former RCA type numbers.

CA D2201 Series devices are diffused-junction silicon ctifiers in an axial-lead package. These devices, which differ nly in their voltage ratings, feature fast recovery times (0.5 s max. from 3.14 A peak) without the "snap" type of turn-off which could result in the generation of transients.

The D2201 series are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications.

AXIMUM RATINGS, *Absolute-Maximum Values:*

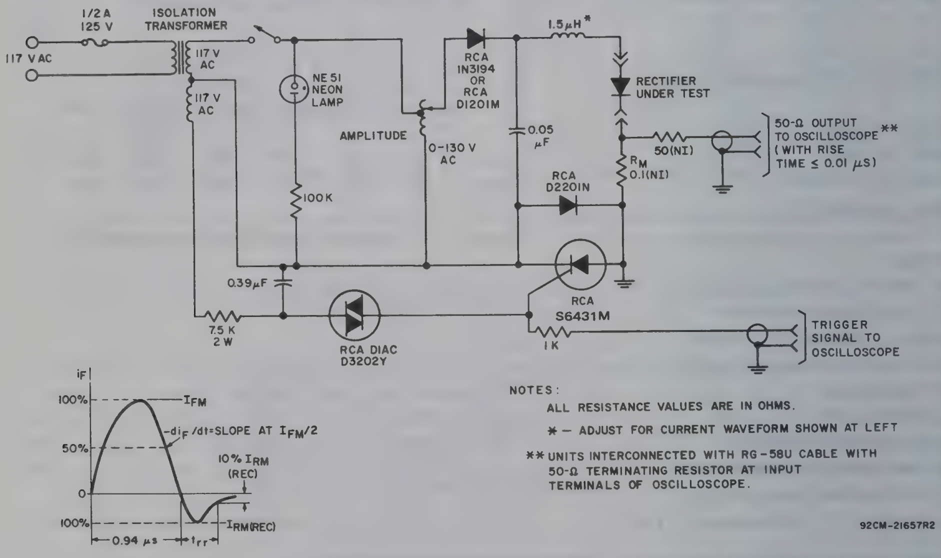
		D2201F	D2201A	D2201B	D2201D	D2201M	D2201N	
EVERSE VOLTAGE:								
REPETITIVE PEAK	V_{RRM}	50	100	200	400	600	800	V
NON-REPETITIVE PEAK	V_{RSM}	100	150	300	500	700	1000	V
ORWARD CURRENT:*								
RMS	$I_{F(RMS)}$	1.5						A
AVERAGE:								
For 180° conduction angle, half sine wave	I_o	1						A
PEAK SURGE (NON-REPETITIVE):								
At junction temperature (T_J) = 150°C								
For one-half cycle of applied voltage, 60 Hz (8.3 ms)	I_{FSM}	50						A
For other durations		See Fig. 3						
PEAK (REPETITIVE)	I_{FRM}	6						A
TORAGE-TEMPERATURE RANGE		−40 to +165						°C
PERATING (JUNCTION) TEMPERATURE		150						°C
EAD TEMPERATURE (During Soldering):								
Measured 1/8 in. (3.17 mm) from case for 10 s max.		255						°C

At lead temperature of 100°C (measured at point on anode lead 1/32 in. (0.8 mm) from the case).

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS		UNITS
		All Types		
		Min.	Max.	
Reverse Current:				
Static:				
For V_{RRM} = max. rated value, $I_F = 0$,	I_{RM}			
$T_J = 25^oC$		–	15	µA
$T_J = 100^oC$		–	250	µA
Instantaneous Forward Voltage Drop: At $i_F = 4$ A, $T_J = 25^oC$ See Fig. 4.	v_F	–	1.9	V
Reverse Recovery Time: For circuit shown in Fig. 1: At $I_{FM} = 3.14$ A, $-di_F/dt = 10$ A/µs, pulse duration = 0.94 µs, $T_C = 25^oC$	t_{rr}	–	0.5	µs
In Tektronix type "S" plug-in unit: At $I_F = 20$ mA, $I_R = 1.0$ mA (DC values) $T_C = 25^oC$		–	1.5	µs
Thermal Resistance (Junction-to-Lead)* See Fig. 14	$R_{\theta JL}$	–	20	$^oC/W$

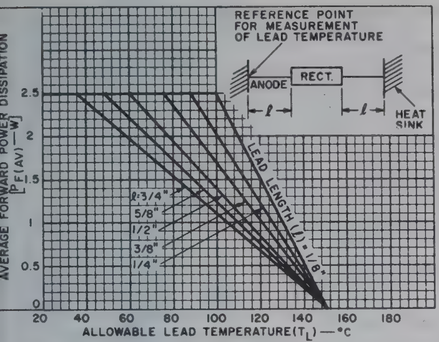
* Measured on anode lead 1/8" (3.18 mm) from case.


1/2 A
125 V
ISOLATION TRANSFORMER
117 V AC
117 V AC
117 V AC
NE 51 NEON LAMP
AMPLITUDE
100 K
0-130 V AC
RCA 1N3194 OR RCA D1201M
1.5µH*
RECTIFIER UNDER TEST
0.05 µF
RCA D2201N
RM 0.1(NI)
50(NI)
50-Ω OUTPUT TO OSCILLOSCOPE** (WITH RISE TIME ≤ 0.01 µS)
0.39µF
7.5 K 2 W
RCA DIAC D3202Y
RCA S6431M
1 K
TRIGGER SIGNAL TO OSCILLOSCOPE
iF
100%
IFM
-diF /dt=SLOPE AT IFM/2
50%
10% IRM (REC)
0
100%
IRM(REC)
0.94 µs
trr

NOTES:
ALL RESISTANCE VALUES ARE IN OHMS.
* – ADJUST FOR CURRENT WAVEFORM SHOWN AT LEFT
** UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE.

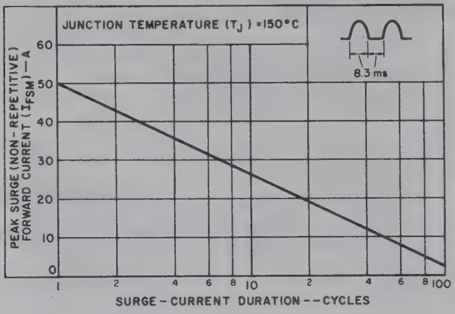
92CM-21657R2

Fig.1 – Oscilloscope display and test circuit for measurement of reverse-recovery time for all types.



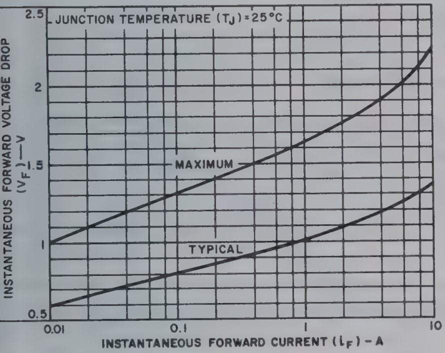
92CS-21660

ig.2 – Average forward power dissipation vs. lead temperature for all types.



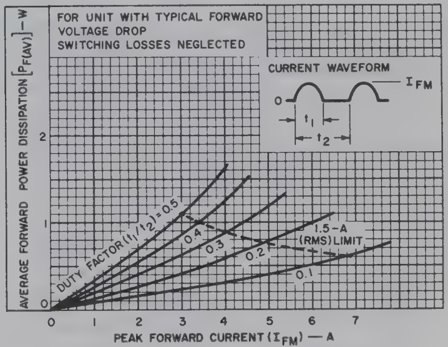
92CS-21658

Fig.3 – Peak surge (non-repetitive) forward current vs. surge-current duration for all types.



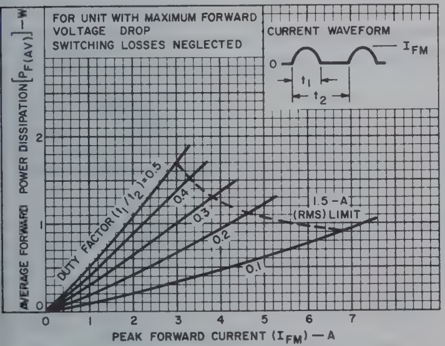
92CS-17520

Fig.4 – Forward voltage drop vs. forward current for all types.



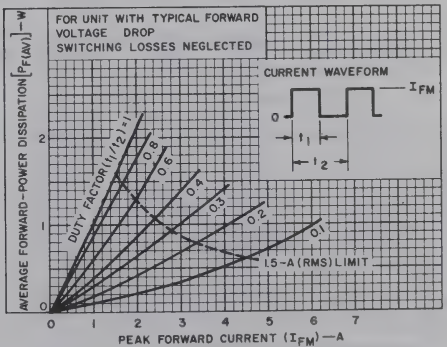
92CS-17521

Fig.5 – Average forward power dissipation (typical) as a function of duty factor for all types.



92CS-17522

Fig.6 – Average forward power dissipation (maximum) as a function of duty factor for all types.



92CS-17523

Fig.7 – Average forward power dissipation (typical) as a function of duty factor for all types.

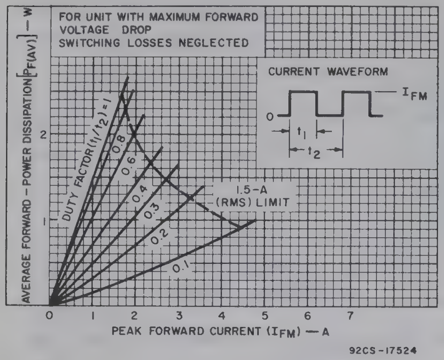


Fig.8 – Average forward power dissipation (maximum) as a function of duty factor for all types.

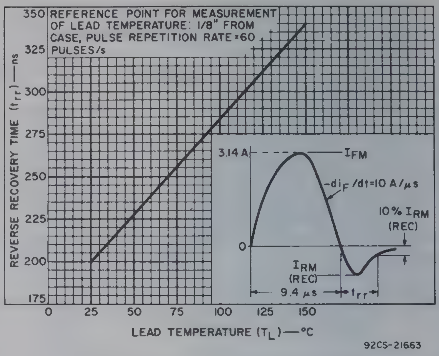


Fig.9 – Typical variation of reverse recovery time with lead temperature for all types.

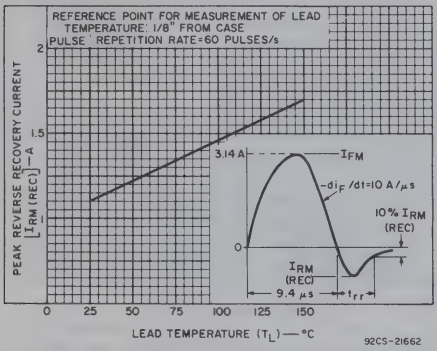


Fig.10 – Peak reverse recovery current vs. lead temperature for all types.

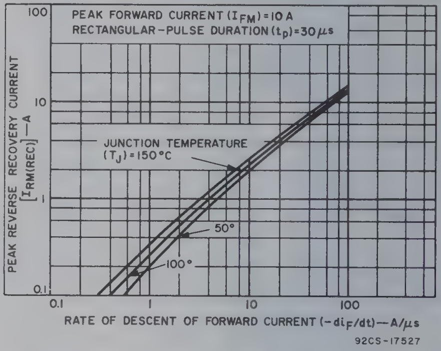


Fig.11 – Peak reverse recovery current vs. rate of descent of forward current for all types.

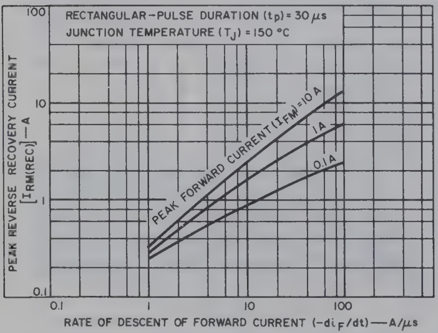


Fig.12 – Peak reverse recovery current vs. rate of descent of forward current for all types.

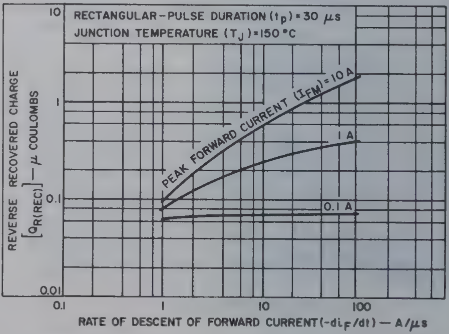
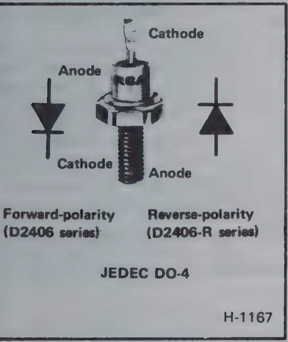


Fig.13 – Reverse recovered charge vs. rate of descent of forward current for all types.

Solid State Division

Rectifiers

D2406 Series
D2406-R Series


Cathode
Anode
Cathode
Anode
Forward-polarity (D2406 series)
Reverse-polarity (D2406-R series)
JEDEC DO-4
H-1167

6-A, 50-to-600-V, Fast-Recovery Silicon Rectifiers

General-Purpose Types for Medium-Current Applications

Available in reverse-polarity versions:
D2406A-R, D2406B-R, D2406C-R, D2406D-R, D2406F-R, D2406M-R

Voltage / Package	50 V Types	100 V Types	200 V Types	300 V Types	400 V Types	600 V Types
DO-4	D2406F (43879)	D2406A (43880)	D2406B (43881)	D2406C (43882)	D2406D (43883)	D2406M (43884)

Numbers in parentheses are former RCA type numbers.

RCA D2406 series and D2406-R series are diffused-junction silicon rectifiers in a stud-type hermetic package. These devices differ only in their voltage ratings.

All types feature fast reverse-recovery time, with "soft" recovery characteristics that reduce the generation of RFI and voltage transients.

These devices are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications.

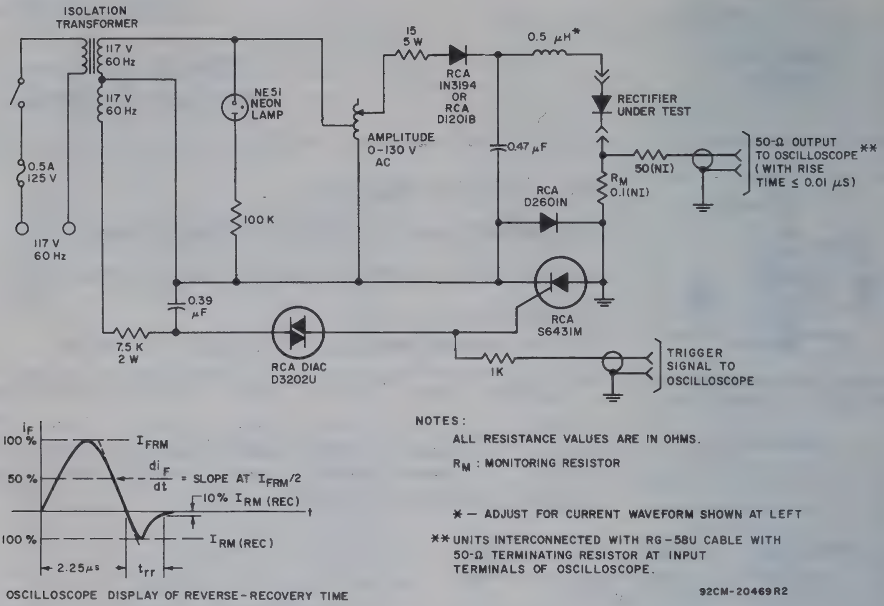
Features:

- Fast reverse-recovery time (t_{rr}) —
  0.35 μs max. (I_{FRM} = 19 A peak, see test circuit Fig. 1)
  0.2 μs max. (I_F = 1 A, I_{RM} = 2 A max., see test circuit Fig. 2)
- Low reverse-recovery current
- Low forward-voltage drop
- Low-thermal-resistance hermetic package

AXIMUM RATINGS, *Absolute-Maximum Values:*

		D2406F D2406F-R	D2406A D2406A-R	D2406B D2406B-R	D2406C D2406C-R	D2406D D2406D-R	D2406M D2406M-R	
EVERSE VOLTAGE:								
Repetitive peak	V_{RRM}	50	100	200	300	400	600	V
Non-repetitive peak	V_{RSM}	100	200	300	400	600	800	V
ORWARD CURRENT (Conduction angle = 180°, half sine wave):								
RMS (T_C) = 100°C)●	$I_{F(RMS)}$	9						A
Average (T_C = 100°C)●	I_o	6						A
Peak-surge (non-repetitive):	I_{FSM}							
At junction temperature (T_J) = 150°C:								
For one-half cycle of applied voltage, 60 Hz (8.3 ms)		125						A
For other durations		See Fig.3						
Peak (repetitive)	I_{FRM}	25						A
TORAGE-TEMPERATURE RANGE		−40 to 165						°C
PERATING (JUNCTION) TEMPERATURE		150						°C
TUD TORQUE:								
Recommended		15						in-lb
Maximum (DO NOT EXCEED)		25						in-lb

● Case temperature is measured at center of any flat surface on the hexagonal head of the mounting stud.


ISOLATION TRANSFORMER
117 V 60 Hz
117 V 60 Hz
0.5A 125 V
117 V 60 Hz
NE51 NEON LAMP
100 K
AMPLITUDE 0-130 V AC
15 5 W
RCA 1N3194 OR RCA D1201B
0.5 μH*
0.47 μF
RECTIFIER UNDER TEST
50(NI)
50-Ω OUTPUT TO OSCILLOSCOPE** (WITH RISE TIME ≤ 0.01 μS)
R_M 0.1(NI)
RCA D2601N
RCA S6431M
0.39 μF
7.5 K 2 W
RCA DIAC D3202U
1K
TRIGGER SIGNAL TO OSCILLOSCOPE
i_F
100 %
50 %
100 %
I_{FRM}
$\frac{di_F}{dt}$ = SLOPE AT $I_{FRM}/2$
10% I_{RM} (REC)
I_{RM} (REC)
t
2.25μs
t_{rr}
OSCILLOSCOPE DISPLAY OF REVERSE-RECOVERY TIME

NOTES:

ALL RESISTANCE VALUES ARE IN OHMS.

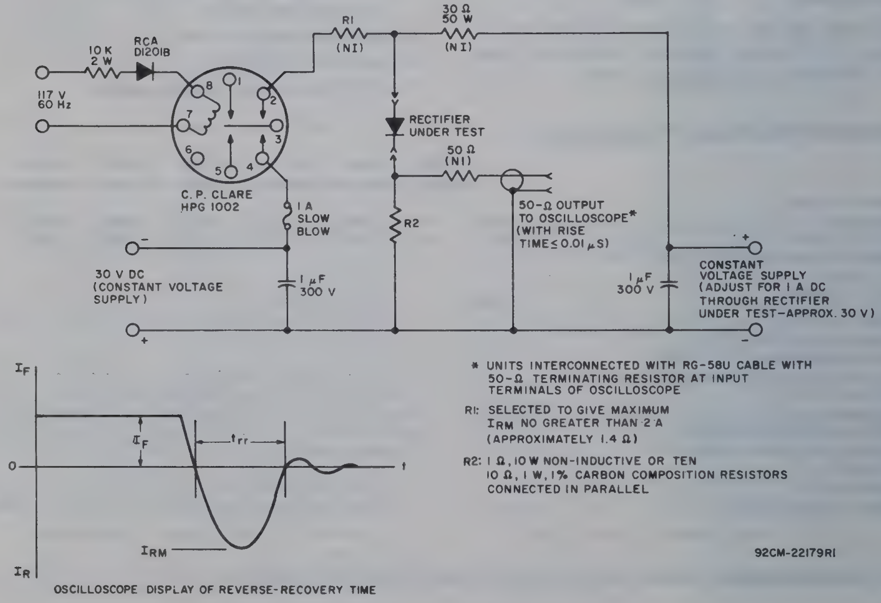
R_M : MONITORING RESISTOR

* — ADJUST FOR CURRENT WAVEFORM SHOWN AT LEFT

** UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE.

92CM-20469R2

Fig.1 — Test circuit (pulsed sine wave) for measurement of reverse-recovery time.


10 K 2 W
RCA D1201B
117 V 60 Hz
C.P. CLARE HPG 1002
1
2
3
4
5
6
7
8
R1 (NI)
30 Ω 50 W (NI)
RECTIFIER UNDER TEST
50 Ω (NI)
50-Ω OUTPUT TO OSCILLOSCOPE* (WITH RISE TIME ≤ 0.01 μS)
R2
1 A SLOW BLOW
30 V DC (CONSTANT VOLTAGE SUPPLY)
1 μF 300 V
1 μF 300 V
CONSTANT VOLTAGE SUPPLY (ADJUST FOR 1 A DC THROUGH RECTIFIER UNDER TEST–APPROX. 30 V)
I_F
I_F
0
t
t_{rr}
I_{RM}
I_R
OSCILLOSCOPE DISPLAY OF REVERSE-RECOVERY TIME

* UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE

R1: SELECTED TO GIVE MAXIMUM I_{RM} NO GREATER THAN 2 A (APPROXIMATELY 1.4 Ω)

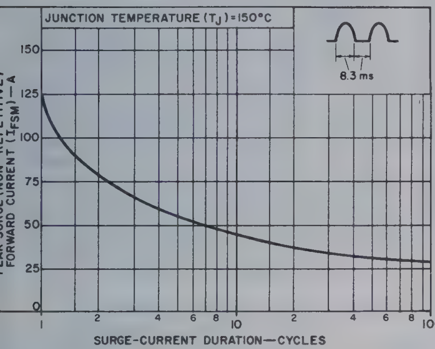
R2: 1 Ω, 10 W NON-INDUCTIVE OR TEN 10 Ω, 1 W, 1% CARBON COMPOSITION RESISTORS CONNECTED IN PARALLEL

92CM-22179R1

Fig.2 — Test circuit (pulsed dc) for measurement of reverse-recovery time.

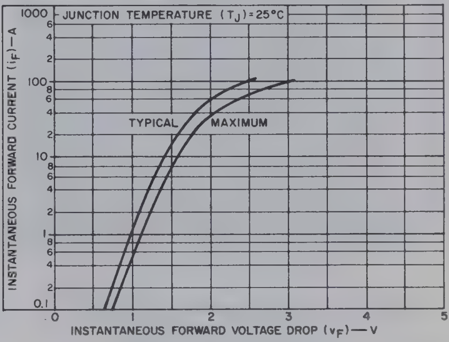
LECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS ALL TYPES		UNITS
		MIN.	MAX.	
everse Current:				
Static				
For V_{RRM} = max. rated value, $I_F = 0$, $T_C = 25^oC$	I_{RM}	–	15	μA
$T_C = 100^oC$		–	3	mA
stantaneous Forward Voltage Drop:				
At i_F 6 A, $T_J = 25^oC$	v_F	–	1.4	V
everse Recovery Time:				
For circuit shown in Fig. 1, at $I_{FM} = 19$ A, $-di_F/dt = 25$ A/μs, pulsed duration = 2.25 μs, $T_C = 25^oC$	t_{rr}	–	0.35	μs
For circuit shown in Fig. 2, at $I_{FM} = 1$ A, $I_{RM} = 2$ A max., $T_C = 25^oC$		–	0.2	
ermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	3	°C/W



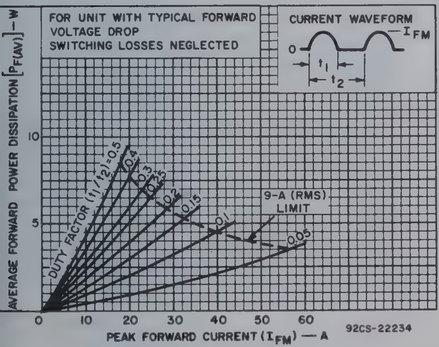
92CS-22232

Fig.3 – Peak surge (non-repetitive) forward current vs. surge-current duration.



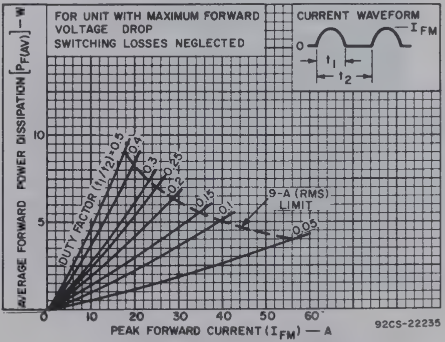
92CS-22233

Fig.4 – Forward current vs. forward voltage drop.



92CS-22234

Fig.5 – Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.



92CS-22235

Fig.6 – Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.

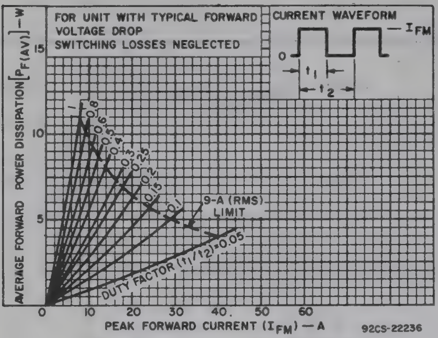


Fig.7 – Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.

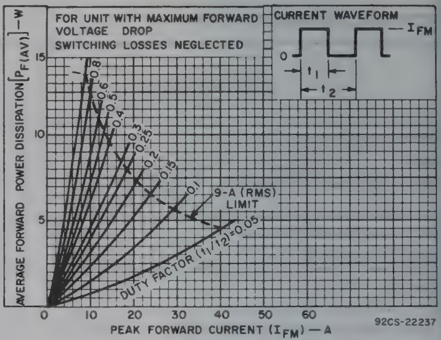
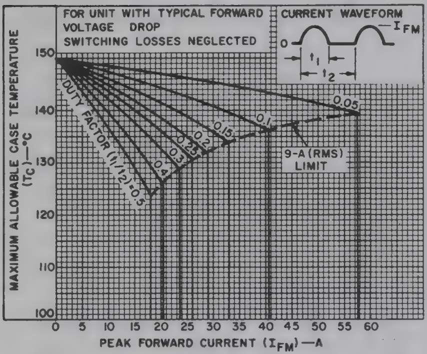
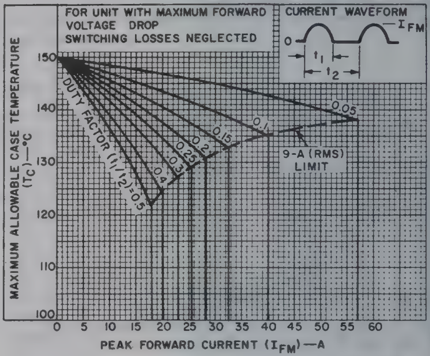


Fig.8 – Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.



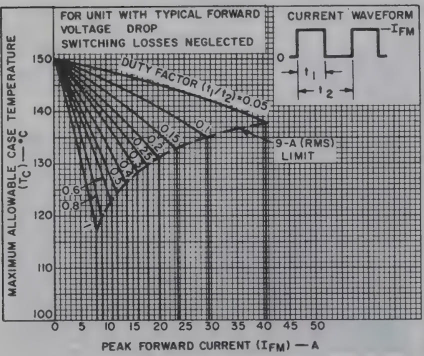
92CS-22238

Fig.9 – Maximum allowable case temperature as a function of peak current and duty factor for units with typical forward voltage drop.



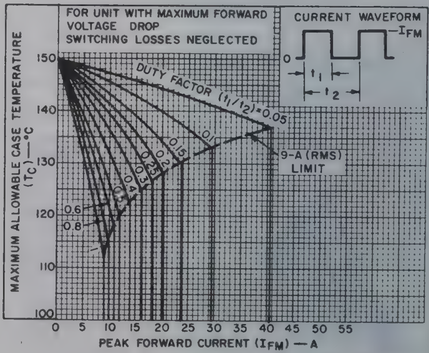
92CS-22239

Fig.10 – Maximum allowable case temperature as a function of peak current and duty factor for units with maximum forward voltage drop.



92CS-22240

Fig.11 – Maximum allowable case temperature as a function of peak current and duty factor for units with typical forward voltage drop.



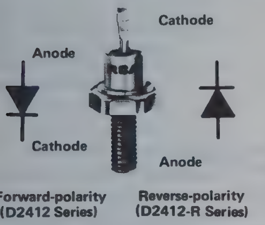
92CS-22241

Fig.12 – Maximum allowable case temperature as a function of peak current and duty factor for units with maximum forward voltage drop.

RCA
Solid State
Division

Rectifiers

D2412 Series
D2412-R Series



JEDEC DO-4

H-1167

12-A, 50-to-600-V, Fast-Recovery Silicon Rectifiers

General-Purpose Types for Medium-Current Applications

Available in reverse-polarity versions:
D2412A-R, D2412B-R, D2412C-R, D2412D-R, D2412F-R, D2412M-R

Package \ Voltage	50 V Type	100 V Type	200 V Type	300 V Type	400 V Type	600 V Type
DO-4	D2412F (43889)	D2412A (43890)	D2412B (43891)	D2412C (43892)	D2412D (43893)	D2412M (43894)

Numbers in parentheses are former RCA type numbers.

CA D2412 series and D2412-R series are diffused-junction icon rectifiers in a stud-type hermetic package. These evices differ only in their voltage ratings.

l types feature fast reverse-recovery time, with "soft" re-very characteristics that reduce the generation of RFI and ltage transients.

ese devices are intended for use in high-speed inverters, oppers, high-frequency rectifiers, "free-wheeling" diode cuits, and other high-frequency applications.

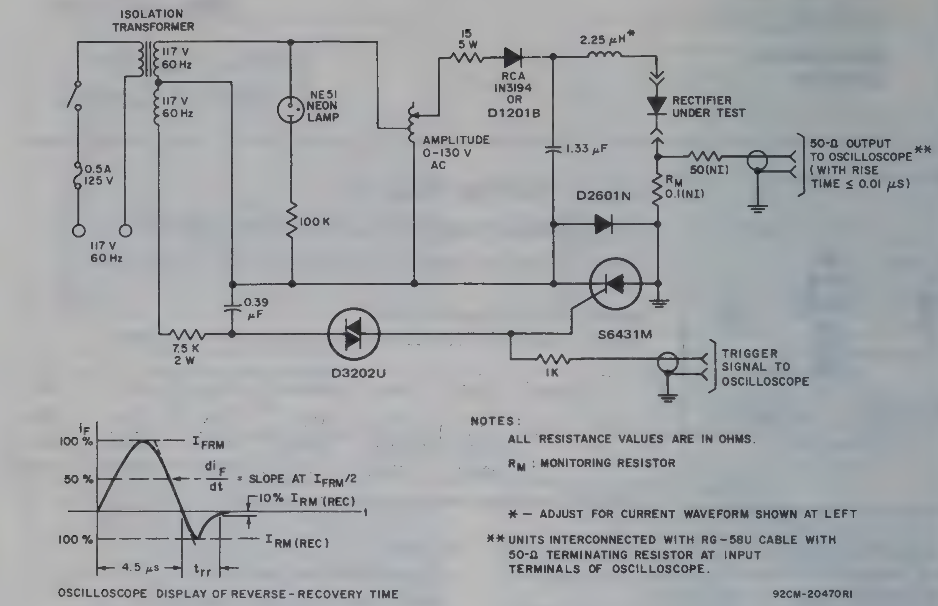
Features:

- Fast reverse-recovery time (t_{rr}) —
  0.35 μs max. (I_{FRM} = 38 A peak, see test circuit Fig. 1)
  0.2 μs max. (I_F = 1 A, I_{RM} = 2 A max., see test circuit Fig. 2)
- Low reverse-recovery current
- Low forward-voltage drop
- Low-thermal-resistance hermetic package

AXIMUM RATINGS, *Absolute-Maximum Values:*

		D2412F D2412F-R	D2412A D2412A-R	D2412B D2412B-R	D2412C D2412C-R	D2412D D2412D-R	D2412M D2412M-R	
EVERSE VOLTAGE:								
Repetitive peak	V_{RRM}	50	100	200	300	400	600	V
Non-repetitive peak	V_{RSM}	100	200	300	400	600	800	V
ORWARD CURRENT (Conduction angle = 180°, half sine wave):								
RMS (T_C = 100°C)●	$I_{F(RMS)}$	18						A
Average (T_C = 100°C)●	I_o	12						A
Peak-surge (non-repetitive):	I_{FSM}							
At junction temperature (T_J) = 150°C:								
For one-half cycle of applied voltage, 60 Hz (8.3 ms)		250						A
For other durations		See Fig.3						
Peak (repetitive)	I_{FRM}	50						A
TORAGE-TEMPERATURE RANGE		−40 to 165						°C
PERATING (JUNCTION) TEMPERATURE		150						°C
TUD TORQUE:								
Recommended		15						in-lb
Maximum (DO NOT EXCEED)		25						in-lb

● Case temperature is measured at center of any flat surface on the hexagonal head of the mounting stud.


ISOLATION TRANSFORMER
117 V 60 Hz
117 V 60 Hz
0.5 A 125 V
117 V 60 Hz
NE51 NEON LAMP
100 K
15 5 W
RCA 1N3194 OR D1201B
AMPLITUDE 0–130 V AC
2.25 μH*
1.33 μF
RECTIFIER UNDER TEST
50-Ω OUTPUT TO OSCILLOSCOPE** (WITH RISE TIME ≤ 0.01 μS)
50(NI)
R_M 0.1(NI)
D2601N
S6431M
0.39 μF
7.5 K 2 W
D3202U
1K
TRIGGER SIGNAL TO OSCILLOSCOPE
i_F
100 %
50 %
100 %
I_FRM
di_F/dt = SLOPE AT I_FRM/2
10% I_RM (REC)
I_RM (REC)
t
4.5 μs
t_rr

OSCILLOSCOPE DISPLAY OF REVERSE-RECOVERY TIME

NOTES:

ALL RESISTANCE VALUES ARE IN OHMS.

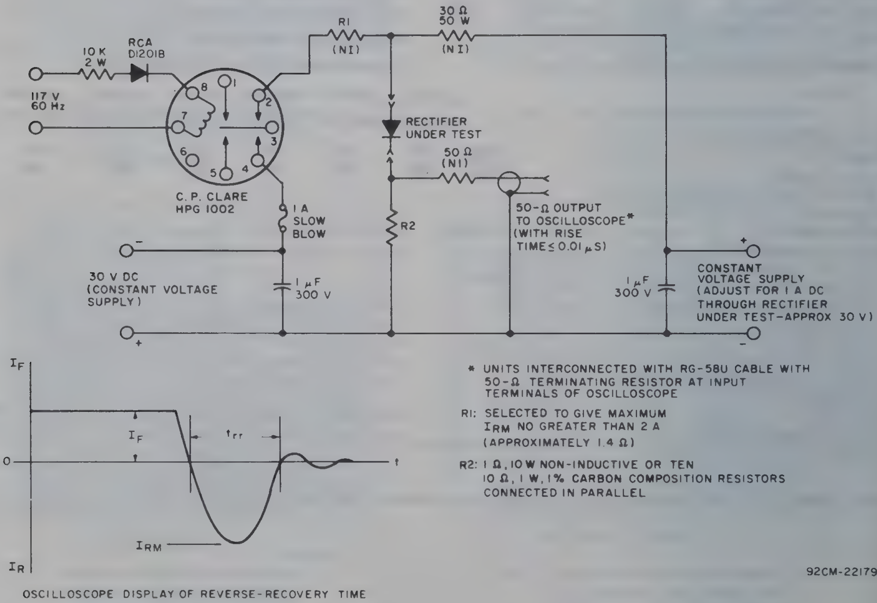
R_M : MONITORING RESISTOR

* — ADJUST FOR CURRENT WAVEFORM SHOWN AT LEFT

** UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE.

92CM-20470R1

Fig.1 — Test circuit (pulsed sine wave) for measurement of reverse-recovery time.


117 V 60 Hz
10 K 2 W
RCA D1201B
C. P. CLARE HPG 1002
1 2 3 4 5 6 7 8
R1 (NI)
30 Ω 50 W (NI)
RECTIFIER UNDER TEST
50 Ω (NI)
R2
50-Ω OUTPUT TO OSCILLOSCOPE* (WITH RISE TIME ≤ 0.01 μS)
1 A SLOW BLOW
30 V DC (CONSTANT VOLTAGE SUPPLY)
1 μF 300 V
1 μF 300 V
CONSTANT VOLTAGE SUPPLY (ADJUST FOR 1 A DC THROUGH RECTIFIER UNDER TEST–APPROX 30 V)
I_F
I_F
0
t
t_rr
I_RM
I_R

* UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE

R1: SELECTED TO GIVE MAXIMUM I_{RM} NO GREATER THAN 2 A (APPROXIMATELY 1.4 Ω)

R2: 1 Ω, 10 W NON-INDUCTIVE OR TEN 10 Ω, 1 W, 1% CARBON COMPOSITION RESISTORS CONNECTED IN PARALLEL

92CM-22179R1

OSCILLOSCOPE DISPLAY OF REVERSE-RECOVERY TIME

Fig.2 — Test circuit (pulsed dc) for measurement of reverse-recovery time.

LECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS		UNITS
		ALL TYPES		
		MIN.	MAX.	
everse Current: *Static* For V_{RRM} = max. rated value, $I_F = 0$, $T_C = 25^oC$	I_{RM}	–	100	μA
$T_C = 100^oC$		–	4	mA
nstantaneous Forward Voltage Drop: At $i_F = 12$ A, $T_J = 25^oC$	v_F	–	1.4	V
everse Recovery Time: For circuit shown in Fig. 1, at $I_{FM} = 38$ A, $-di_F/dt = 25$ A/μs, pulse duration = 4.5 μs, $T_C = 25^oC$	t_{rr}	–	0.35	μs
For circuit shown in Fig. 2, at $I_{FM} = 1$ A, $I_{RM} = 2$ A max., $T_C = 25^oC$		–	0.2	
hermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	1.5	°C/W

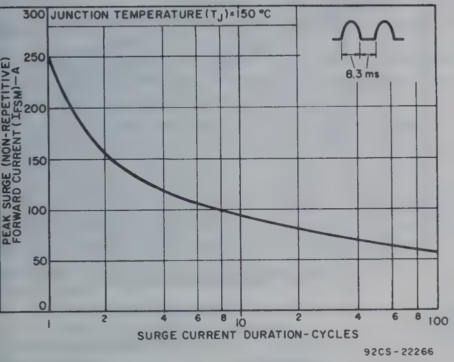


Fig.3 – Peak surge (non-repetitive) forward current vs. surge-current duration.

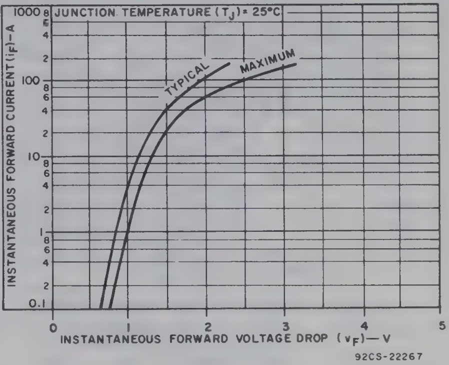


Fig.4 – Forward current vs. forward voltage drop.

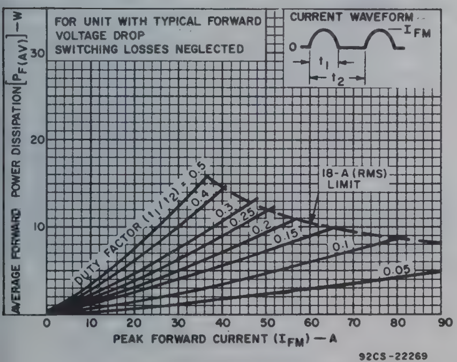


Fig.5 – Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.

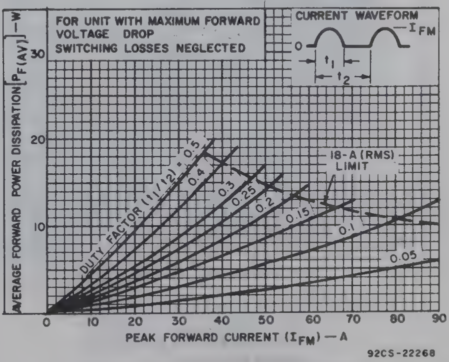


Fig.6 – Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.

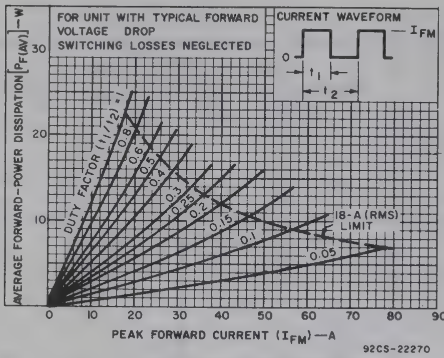


Fig.7 – Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.

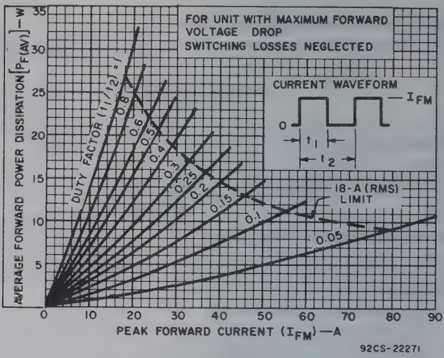


Fig.8 – Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.

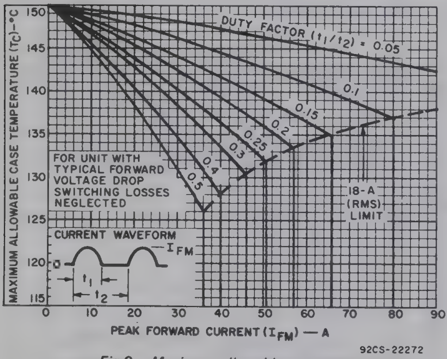


Fig.9 – Maximum allowable case temperature as a function of peak current and duty factor for units with typical forward voltage drop.

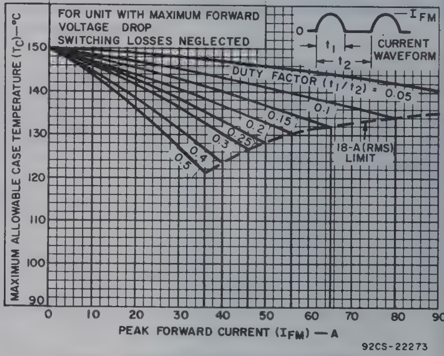


Fig.10 – Maximum allowable case temperature as a function of peak current and duty factor for units with maximum forward voltage drop.

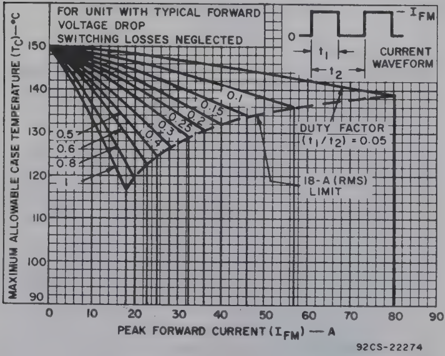


Fig.11 – Maximum allowable case temperature as a function of peak current and duty factor for units with typical forward voltage drop.

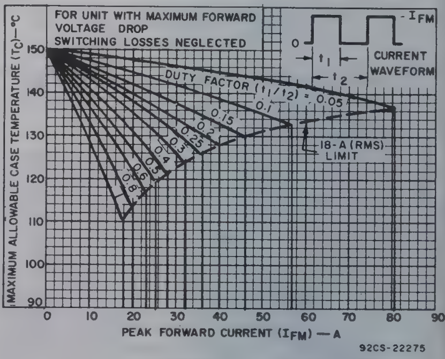
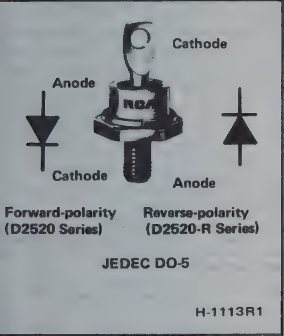


Fig.12 – Maximum allowable case temperature as a function of peak current and duty factor for units with maximum forward voltage drop.

Solid State
Division

Rectifiers

D2520 Series
D2520-R Series



20-A, 50-to-600-V, Fast-Recovery Silicon Rectifiers

General-Purpose Types for High-Current Applications

Available in reverse-polarity versions:
D2520A-R, D2520B-R, D2520C-R, D2520D-R, D2520F-R, D2520M-R

Package \ Voltage	50 V Types	100 V Types	200 V Types	300 V Types	400 V Types	600 V Types
DO-5	D2520F (43899)	D2520A (43900)	D2520B (43901)	D2520C (43902)	D2520D (43903)	D2520M (43904)

Numbers in parentheses are former RCA type numbers.

RCA D2520 series and D2520-R series are diffused-junction ilicon rectifiers in a stud-type hermetic package. These levices differ only in their voltage ratings.

All types feature fast reverse-recovery time, with "soft" re-covery characteristics that reduce the generation of RFI and oltage transients.

These devices are intended for use in high-speed inverters, hoppers, high-frequency rectifiers, "free-wheeling" diode ircuits, and other high-frequency applications.

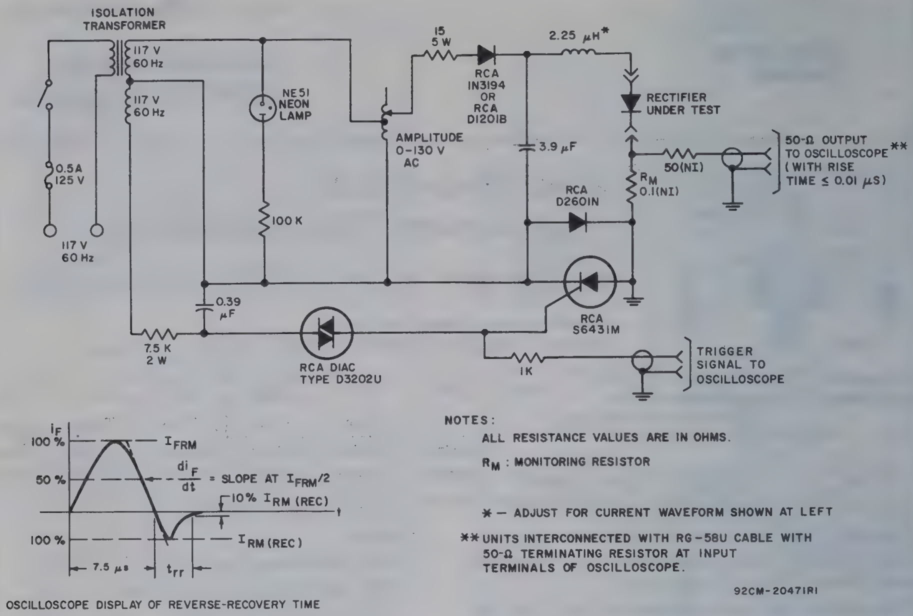
Features:

- Fast reverse-recovery time (t_{rr}) –
  0.35 µs max. (I_{FRM} = 63 A peak, see test circuit Fig. 1)
  0.2 µs max. (I_{RM} = 1 A, I_{RM} = 2 A max., see test circuit Fig. 2)
- Low reverse-recovery current
- Low forward-voltage drop
- Low-thermal-resistance hermetic package

AXIMUM RATINGS, *Absolute-Maximum Values:*

		D2520F D2520F-R	D2520A D2520A-R	D2520B D2520B-R	D2520C D2520C-R	D2520D D2520D-R	D2520M D2520M-R	
EVERSE VOLTAGE:								
Repetitive peak	V_{RRM}	50	100	200	300	400	600	V
Non-repetitive peak	V_{RSM}	100	200	300	400	600	800	V
ORWARD CURRENT (Conduction angle = 180°, half sine wave):								
RMS (T_C = 100°C)●	$I_{F(RMS)}$	30						A
Average (T_C = 100°C)●	I_o	20						A
Peak-surge (non-repetitive):	I_{FSM}							
At junction temperature (T_J) = 150°C:								
For one-half cycle of applied voltage, 60 Hz (8.3 ms)		300						A
For other durations		See Fig.3						
Peak (repetitive)	I_{FRM}	100						A
TORAGE-TEMPERATURE RANGE		–40 to 165						°C
PERATING (JUNCTION) TEMPERATURE		150						°C
TUD TORQUE:								
Recommended		30						in-lb
Maximum (DO NOT EXCEED)		50						in-lb

● Case temperature is measured at center of any flat surface on the hexagonal head of the mounting stud.


ISOLATION TRANSFORMER
117 V 60 Hz
117 V 60 Hz
0.5A 125 V
117 V 60 Hz
NE51 NEON LAMP
100 K
AMPLITUDE 0-130 V AC
15 5 W
RCA 1N3194 OR RCA D1201B
2.25 μH*
RECTIFIER UNDER TEST
3.9 μF
RCA D2601N
50(NI)
RM 0.1(NI)
50-Ω OUTPUT TO OSCILLOSCOPE** (WITH RISE TIME ≤ 0.01 μS)
RCA S6431M
0.39 μF
7.5 K 2 W
RCA DIAC TYPE D3202U
1K
TRIGGER SIGNAL TO OSCILLOSCOPE
iF
100 %
50 %
100 %
IFRM
diF/dt = SLOPE AT IFRM/2
10% IRM (REC)
IRM (REC)
t
7.5 μs
trr
OSCILLOSCOPE DISPLAY OF REVERSE-RECOVERY TIME

NOTES:

ALL RESISTANCE VALUES ARE IN OHMS.

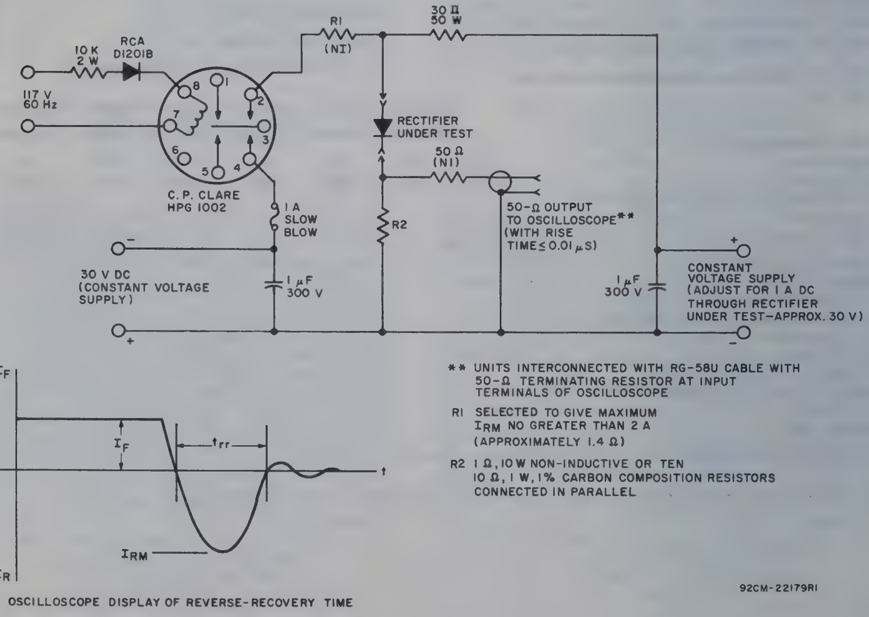
R_M : MONITORING RESISTOR

* — ADJUST FOR CURRENT WAVEFORM SHOWN AT LEFT

** UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE.

92CM-20471R1

Fig.1 — Test circuit (pulsed sine wave) for measurement of reverse-recovery time.


117 V 60 Hz
10 K 2 W
RCA D1201B
R1 (NI)
30 Ω 50 W
8
1
2
7
3
6
5
4
C. P. CLARE HPG 1002
1 A SLOW BLOW
RECTIFIER UNDER TEST
50 Ω (NI)
R2
50-Ω OUTPUT TO OSCILLOSCOPE** (WITH RISE TIME≤ 0.01 μS)
30 V DC (CONSTANT VOLTAGE SUPPLY)
1 μF 300 V
1 μF 300 V
CONSTANT VOLTAGE SUPPLY (ADJUST FOR 1 A DC THROUGH RECTIFIER UNDER TEST–APPROX. 30 V)
IF
IF
0
trr
t
IRM
IR
OSCILLOSCOPE DISPLAY OF REVERSE-RECOVERY TIME

** UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE

R1 SELECTED TO GIVE MAXIMUM I_{RM} NO GREATER THAN 2 A (APPROXIMATELY 1.4 Ω)

R2 1 Ω, 10 W NON-INDUCTIVE OR TEN 10 Ω, 1 W, 1% CARBON COMPOSITION RESISTORS CONNECTED IN PARALLEL

92CM-22179R1

Fig.2 — Test circuit (pulsed dc) for measurement of reverse-recovery time.

LECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS		UNITS
		ALL TYPES		
		MIN.	MAX.	
everse Current:				
Static				
For V_{RRM} = max. rated value, $I_F = 0$, $T_C = 25^oC$	I_{RM}	–	0.05	µA
$T_C = 100^oC$		–	6	mA
nstantaneous Forward Voltage Drop:				
At $i_F = 20$ A, $T_J = 25^oC$	v_F	–	1.4	V
everse Recovery Time:				
For circuit shown in Fig. 1, at				
$I_{FM} = 63$ A, $-di_F/dt = 25$ A/µs,				
pulse duration = 7.5 µs, $T_C = 25^oC$	t_{rr}	–	0.35	µs
For circuit shown in Fig. 2, at				
$I_{FM} = 1$ A, $I_{RM} = 2$ A max., $T_C = 25^oC$		–	0.2	
hermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	1	°C/W

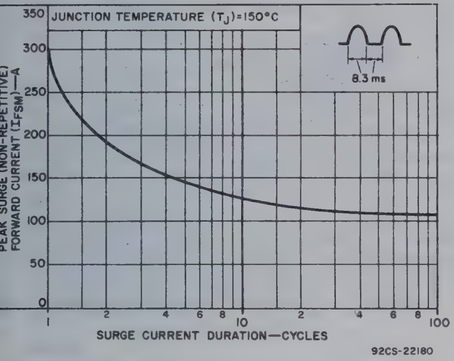


Fig.3 – Peak surge (non-repetitive) forward current vs. surge-current duration.

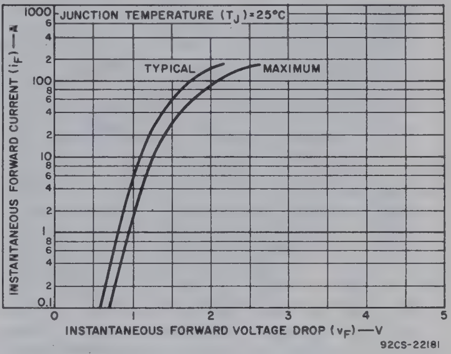


Fig.4 – Forward current vs. forward voltage drop.

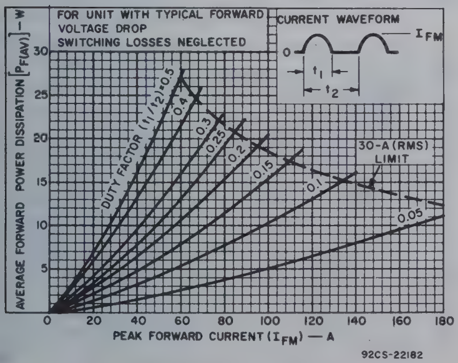


Fig.5 – Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.

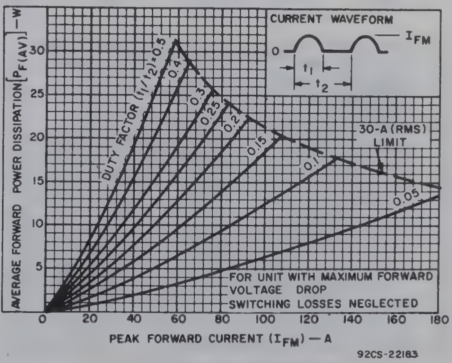
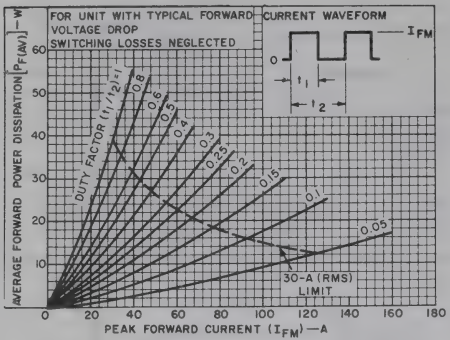
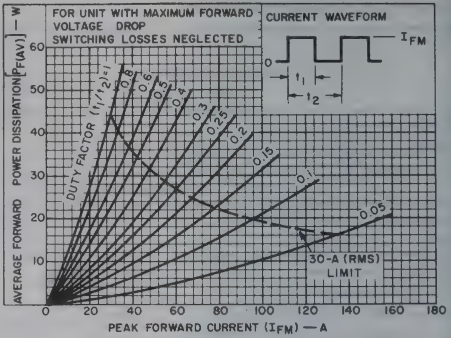


Fig.6 – Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.



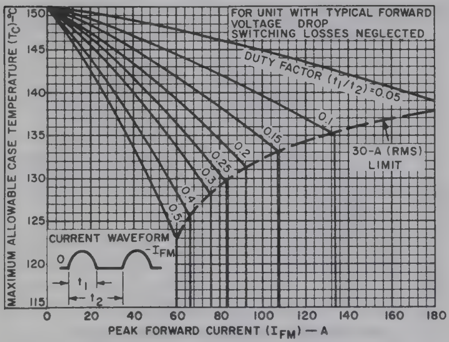
92CS-22184

Fig.7 — Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.



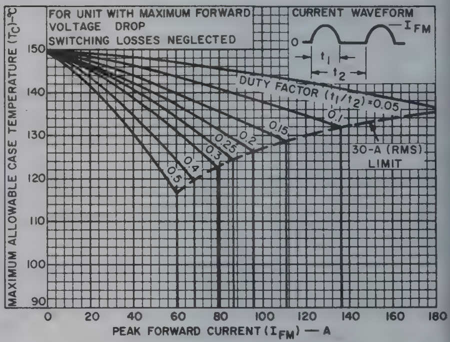
92CS-22185

Fig.8 — Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.



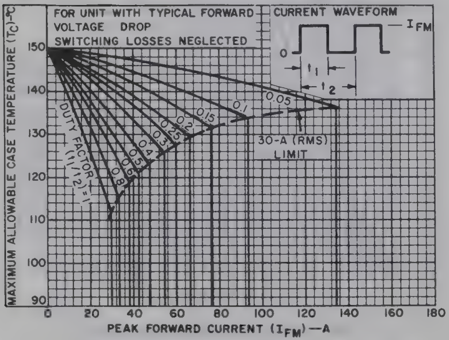
92CS-22186

Fig.9 — Maximum allowable case temperature as a function of peak current and duty factor for units with typical forward voltage drop.



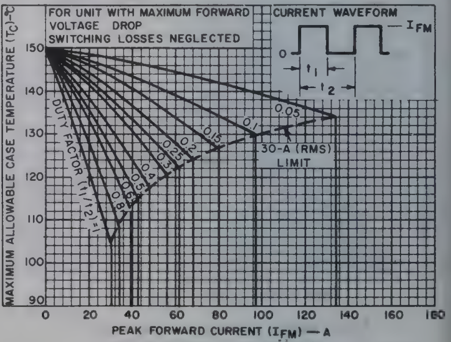
92CS-22187

Fig.10 — Maximum allowable case temperature as a function of peak current and duty factor for units with maximum forward voltage drop.



92CS-22188

Fig.11 — Maximum allowable case temperature as a function of peak current and duty factor for units with typical forward voltage drop.



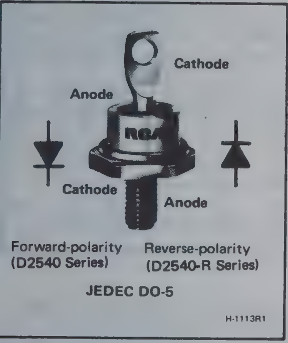
92CS-22189

Fig.12 — Maximum allowable case temperature as a function of peak current and duty factor for units with maximum forward voltage drop.

RCA
Solid State Division

Rectifiers

D2540 Series
D2540-R Series


Cathode
Anode
Cathode
Anode
Forward-polarity (D2540 Series)
Reverse-polarity (D2540-R Series)
JEDEC DO-5
H-1113R1

40-A, 50- to- 600 V, Fast-Recovery Silicon Rectifiers

General Purpose Types for High-Current Applications

Featutes:

- Available in reverse-polarity versions: D2540A-R, D2540B-R, D2540D-R, D2540F-R, D2540M-R
- Fast reverse-recovery time — 0.35 μs max. from 125 A peak
- Low reverse-recovery current
- Low forward-voltage drop
- Low-thermal-resistance hermetic package

Package \ Voltage	50 V Types	100 V Types	200 V Types	400 V Types	600 V Types
DO-5	D2540F (40956)	D2540A (40957)	D2540B (40958)	D2540D (40959)	D2540M (40960)
DO-5	D2540F-R (40956R)	D2540A-R (40957R)	D2540B-R (40958R)	D2540D-R (40959R)	D2540M-R (40960R)

Numbers in parentheses are former RCA type numbers.

RCA D2540 series and D2540-R series‡ inclusive, are diffused-junction-type silicon rectifiers in a stud-type hermetic package. These devices differ only in their voltage atings.

All types feature fast reverse-recovery time (0.35 μs max. rom 125 A peak) with "soft" recovery characteristics that reduce the generation of RFI and voltage transients.

These devices are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications.

---

‡ Types D2540A-R, B-R, D-R, and M-R were formerly RCA Dev. Nos. TA7984-TA7987, respectively.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		D2540F D2540F-R	D2540A D2540A-R	D2540B D2540B-R	D2540D D2540D-R	D2540M D2540M-R	
REVERSE VOLTAGE							
Repetitive peak	V_{RRM}	50	100	200	400	600	V
Non-repetitive peak	V_{RSM}	100	200	300	600	800	V
ORWARD CURRENT (Conduction angle = 180°, half sine wave):							
RMS (T_C = 100°C)●	$I_{F(RMS)}$	← 60 →					A
Average (T_C = 100°C)●	I_o	← 40 →					A
Peak-surge (non-repetitive): At junction temperature (T_J) = 150°C For one-half cycle of applied voltage, 60 Hz (8.3 ms)	I_{FSM}	← 700 →					A
Peak (repetitive)	I_{FRM}	← 195 →					A
EMPERATURE RANGE:							
Storage and Operating (Junction)		← -40 to 150 →					°C

Case temperature is measured at center of any flat surface on the heagonal head of the mounting stud.

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS ALL TYPES MIN.	 MAX.	UNITS
Reverse Current: *Static* For V_{RRM} = max. rated value, $I_F = 0$, $T_C = 25^oC$	I_{RM}	–	100	µA
$T_C = 100^oC$		–	2.5	mA
Instantaneous Forward Voltage Drop: At $i_F = 100$ A, $T_J = 25^oC$, See Figure 2.	v_F	–	1.8	V
Reverse-Recovery Time: For circuit shown in Figure 1: At $I_{FRM} = 125$ A, di/dt = 25 A/µs, pulse duration = 15 µs $T_C = 25^oC$	t_{rr}	--	0.35	µs
Thermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	0.9	°C/W

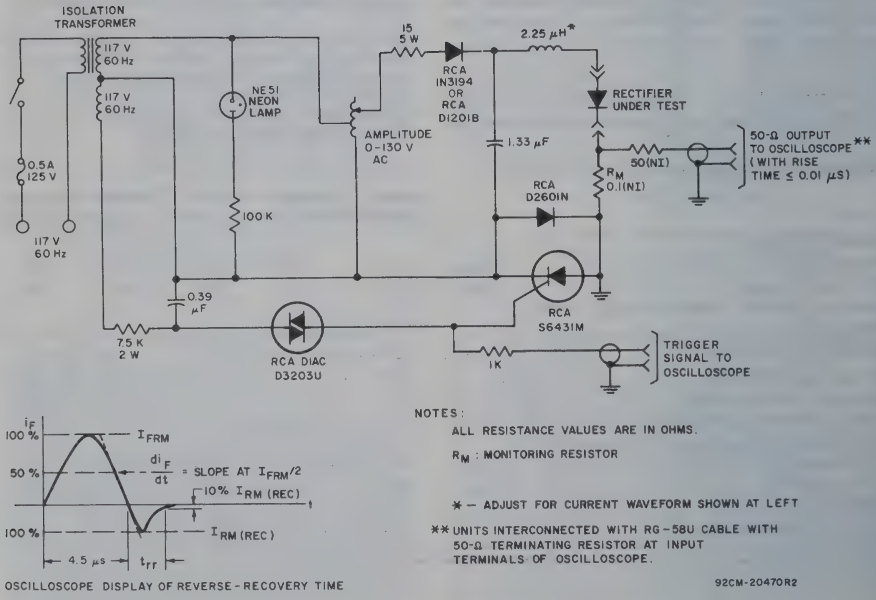

ISOLATION TRANSFORMER
117 V 60 Hz
117 V 60 Hz
0.5 A 125 V
117 V 60 Hz
NE 51 NEON LAMP
100 K
15 5 W
RCA 1N3194 OR RCA D1201B
AMPLITUDE 0-130 V AC
2.25 µH*
RECTIFIER UNDER TEST
1.33 µF
50(NI)
R_M 0.1(NI)
50-Ω OUTPUT TO OSCILLOSCOPE** (WITH RISE TIME ≤ 0.01 µS)
RCA D2601N
RCA S6431M
0.39 µF
7.5 K 2 W
RCA DIAC D3203U
1K
TRIGGER SIGNAL TO OSCILLOSCOPE
i_F
100 %
50 %
100 %
I_{FRM}
$\frac{di_F}{dt}$ = SLOPE AT $I_{FRM}/2$
10% $I_{RM(REC)}$
$I_{RM(REC)}$
4.5 µs
t_{rr}
t
OSCILLOSCOPE DISPLAY OF REVERSE-RECOVERY TIME
NOTES:
ALL RESISTANCE VALUES ARE IN OHMS.
R_M : MONITORING RESISTOR
* – ADJUST FOR CURRENT WAVEFORM SHOWN AT LEFT
** UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE.
92CM-20470R2

Fig. 1—Oscilloscope display and test circuit for measurement of reverse-recovery time.

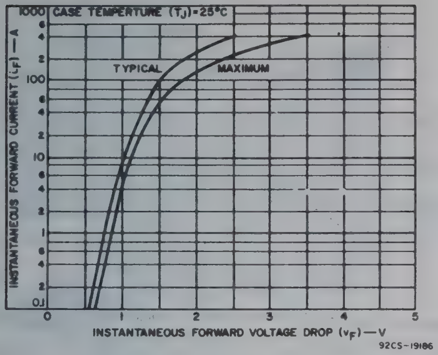


Fig.2—Forward current as a function of forward voltage drop.

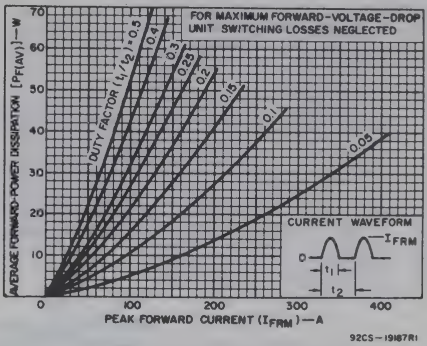


Fig.3—Average forward-power dissipation for maximum forward-voltage-drop unit.

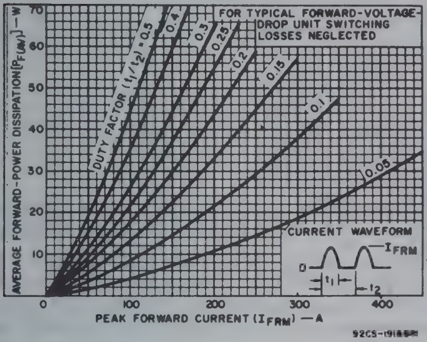


Fig.4—Average forward-power dissipation for typical forward-voltage-drop unit.

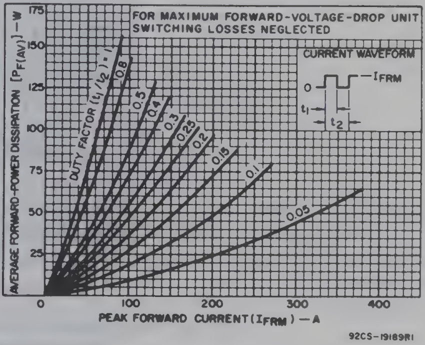


Fig.5—Average forward-power dissipation for maximum forward-voltage-drop unit.

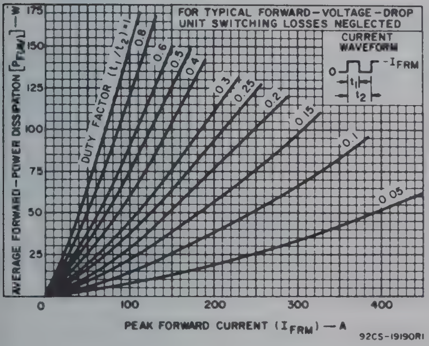


Fig.6—Average forward-power dissipation for typical forward-voltage-drop unit.

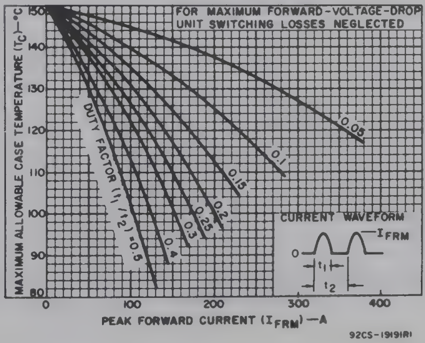


Fig.7—Maximum allowable case temperature for maximum forward-voltage-drop unit.

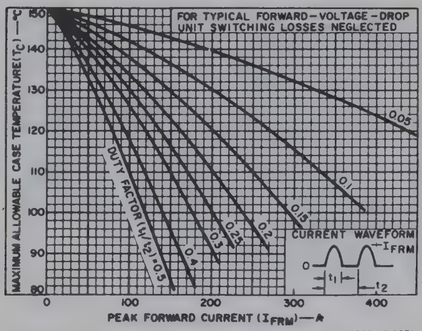


Fig.8—Maximum allowable case temperature for typical forward-voltage-drop unit.

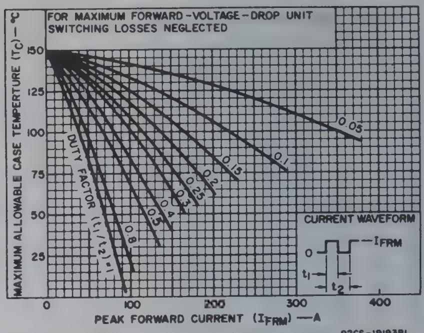


Fig.9—Maximum allowable case temperature for maximum forward-voltage-drop unit.

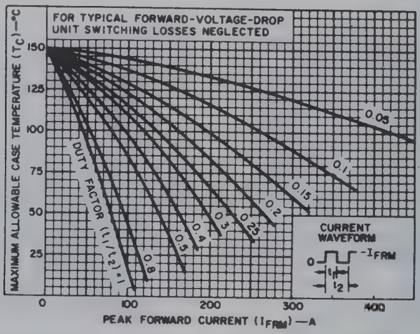
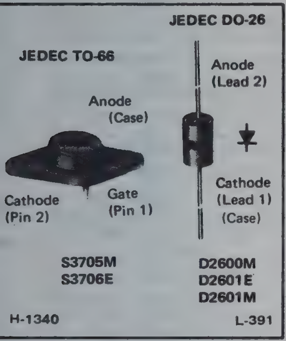


Fig.10—Maximum allowable case temperature for typical forward-voltage-drop unit.

RCA
Solid State Division

Thyristors/Rectifiers
S3705M D2600M
S3706E D2601E
D2601M


JEDEC DO-26
JEDEC TO-66
Anode (Lead 2)
Anode (Case)
Cathode (Pin 2)
Gate (Pin 1)
Cathode (Lead 1) (Case)
S3705M
S3706E
D2600M
D2601E
D2601M
H-1340
L-391

SCR's and Rectifiers for Horizontal-Deflection Circuits

For Large-Screen Color TV

Features:

- Ability to handle high beam current; average 1.6 mA dc
- Ability to supply as much as 5 mJ of stored energy to the deflection yoke, which is sufficient for 29-mm-neck and 36.5-mm-neck picture tubes operated at 29 kV (nominal value)
- Highly reliable circuit which can also be used as a low-voltage power supply

Package \ Voltage	600 V Types	500 V Types
TO-66	S3705M	S3706E
DO-26	D2600M, D2601M	D2601E

hese RCA types are designed for use in a horizontal output ircuit such as that shown in Fig. 1.

he S3705M silicon controlled rectifier and the D2601M ilicon rectifier are designed to act as a bipolar switch that ontrols horizontal yoke current during the beam trace interval. he S3706E silicon controlled rectifier and the D2601E silicon rectifier act as the commutating switch to initiate trace-retrace switching and control yoke current during retrace.

The D2600M silicon rectifier may be used as a clamp to protect the circuit components from excessively high transient voltages which may be generated as a result of arcing in the picture tube or in a high-voltage rectifier tube.

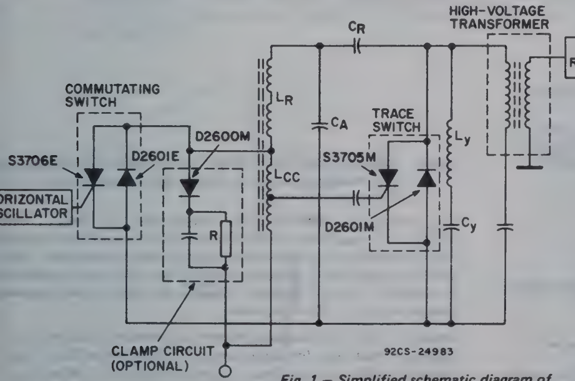

HIGH-VOLTAGE TRANSFORMER
CR
HV RECT.
TO PICTURE TUBE
COMMUTATING SWITCH
LR
CA
TRACE SWITCH
Ly
D2600M
S3706E
D2601E
S3705M
LCC
ORIZONTAL SCILLATOR
D2601M
Cy
R
CLAMP CIRCUIT (OPTIONAL)
B+
92CS-24983

Fig. 1 – Simplified schematic diagram of horizontal output circuit.

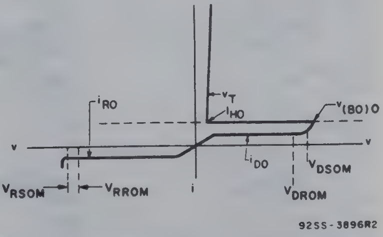


Fig.2 – Principal voltage-current characteristic for S3705M and S3706E.

SILICON CONTROLLED RECTIFIERS

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		S3705M TRACE SCR	S3706E COMMUTATING SCR	
NON-REPETITIVE PEAK OFF-STATE VOLTAGE:•				
Gate Open	V_{DSOM}	700*	600*	V
REPETITIVE PEAK REVERSE VOLTAGE:•				
Gate Open	V_{RROM}	25	25	V
REPETITIVE PEAK OFF-STATE VOLTAGE:•				
Gate Open	V_{DROM}	600	500	V
ON-STATE CURRENT:				
$T_C = 60^oC$, 60 Hz sine wave, conduction angle = 180°.				
RMS	$I_{T(RMS)}$	5	5	A
Average DC	$I_{T(AV)}$	3.2	3.2	A
PEAK SURGE (NON–REPETITIVE) ON-STATE CURRENT:	I_{TSM}			
For one full cycle of applied principal voltage				
60 Hz (sinusoidal), $T_C = 60^oC$		80	80	A
50 Hz (sinusoidal), $T_C = 60^oC$		65	65	A
For one-half sine wave, 3 ms pulse width		150	150	A
RATE OF CHANGE OF ON-STATE CURRENT:				
$V_D = V_{DROM}$, $I_{GT} = 50$ mA, $t_r = 0.1$ μs	di/dt	200	200	A/μs
FUSING CURRENT (for SCR protection):				
$T_J = -40$ to 80^oC, t = 1 to 10 ms	I^2t	20	20	A^2s
GATE POWER DISSIPATION:■	P_{GM}			
Peak (forward or reverse) for 10 μs duration, max.				
negative gate bias = −35 V (S3705M)		25	–	W
= −10 V (S3706E)		–	25	W
TEMPERATURE RANGE:▲				
Storage	T_{stg}	−40 to 150	−40 to 150	°C
Operating (Case)	T_C	−40 to 80	−40 to 80	°C
PIN TEMPERATURE (During soldering):				
At distances ≥ 1/32 in. (0.8 mm) from seating plane for 10 s max.	T_P	225	225	°C

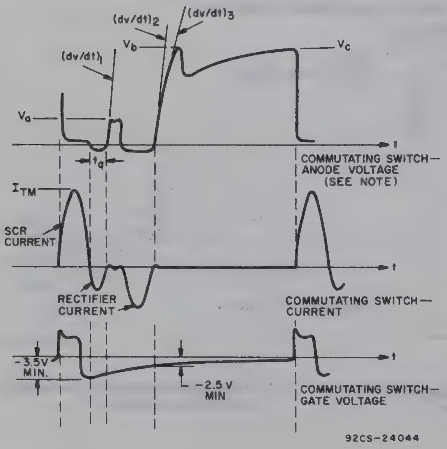
---

*Protection against transients above these values induced by arcing or other causes must be provided.

•These values do not apply if there is a positive gate signal. Gate must be open or negatively biased.

■Any product of gate current and gate voltage which results in a gate power less than the maximum is permitted, provided that the maximum reverse gate bias (as specified) is not exceeded.

▲For temperature measurement reference point, see Dimensional Outline.



NOTE: "Commutating Switch-Anode Voltage" oscilloscope display has been modified graphically to show the measurement points of dv/dt more effectively.

I_{TM} = 15 A, V_a = 100 V max., V_b = 250 V max., V_c = 400. Gate voltage = 12 V positive from 15 V supply. Gate current should rise to 100 mA within 0.2 μs. Minimum duration of gate current pulse = 3 μs. Minimum amplitude of gate current pulse = 200 mA. Negative gate bias at turn-off = −3.5 V minimum, negative gate bias at 2nd reapplied voltage $(dv/dt)_2$ = −2.5 V minimum.

$(dv/dt)_1$ = 400 V/μs (measured tangent to waveform at 0.8 of V_a)
$(dv/dt)_2$ = 1000 V/μs (measured tangent to waveform at 0.3 of V_b)
$(dv/dt)_3$ = 700 V/μs (measured tangent to waveform at 0.8 of V_b)

Fig.3 — Oscilloscope display of commutating switching (S3706E) showing circuit-commutated turn-off time (tq).

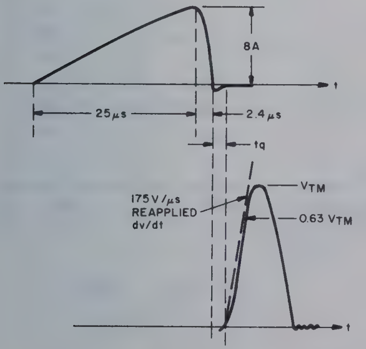
SILICON CONTROLLED RECTIFIERS

ELECTRICAL CHARACTERISTICS

At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS				UNITS
		S3705M TRACE SCR		S3706E COMMUTATING SCR		
		TYP.	MAX.	TYP.	MAX.	
Peak Forward Off-State Current: Gate open, $V_D = V_{DROM}$ $T_C = 85°C$ . .	I_{DOM}	0.5	1.5	0.5	1.5	mA
Instantaneous On-State Voltage: i_T = 30 A (peak), $T_C = 25°C$	v_T	2.2	3	2.2	3	V
Critical Rate of Rise of Off-State Voltage: $V_D = V_{DROM}$, exponential voltage rise, $T_C = 70°C$	dv/dt	175 (min.) (See Fig.4)		1000 (min.) $(dv/dt)_2$ (See Fig.3)		V/µs
DC Gate Trigger Current: V_D = 12 V (dc), $R_L = 30\ \Omega$, $T_C = 25°C$	I_{GT}	15	32	15	45	mA
DC Gate Trigger Voltage: V_D = 12 V (dc), $R_L = 30\ \Omega$, $T_C = 25°C$	V_{GT}	1.8	4	1.8	4	V
Circuit Commutated Turn-Off Time:◆ $T_C = 70°C$, minimum negative gate bias during turn-off time = −20 V (S3705M) and −2.5 V (S3706E), rate of reapplied voltage (dv/dt) = 175 V/µs (See Fig. 4) . . . . = 400 V/µs (See Fig. 3	t_q	– –	2.5 –	– –	– 4.5	µs µs
Thermal Resistance, Junction-to-Case . . .	$R_{\theta JC}$	–	4	–	4	°C/W

◆ This parameter, the sum of reverse recovery time and gate recovery time, is measured from the zero crossing of current to the start of the reapplied voltage. Knowledge of the current, the reapplied voltage, and the case temperature is necessary when measuring t_q. In the worst conditions (high line, zero-beam, off-frequency, minimum auxiliary load, etc.), turn-off time must not fall below the given values. Turn-off time increases with temperature, therfore, case temperature must not exceed 70°C. See Figs. 3 and 4.



I_{TM} = 8 A, $V_{TM} = V_{DROM}$, reapplied dv/dt = 175 V/µs (measured from 0 to 0.63 of V_{TM}); negative gate voltage source = −24 V, source impedance = 15 Ω.

92CS–24045

Fig.4 – Oscilloscope display of trace switching (S3705M) showing circuit-commutating turn-off time (tq).

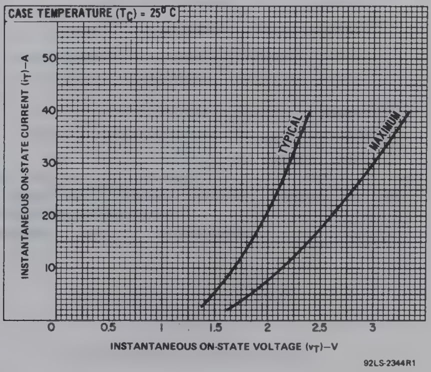


Fig.5 – Instantaneous on-state current vs. on-state voltage for S3705M and S3706E.

SILICON RECTIFIERS

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		D2601M TRACE	D2601E COMMUTATING	D2600M CLAMP	
REVERSE VOLTAGE:**					
Repetitive Peak	V_{RRM}	600	500	600	V
Non-Repetitive Peak●●	V_{RSM}	700	600	700	V
FORWARD CURRENT (operating in 15 kHz deflection circuit):					
RMS	$I_{F(RMS)}$	1.9■■	1.6■■	0.5**	A
Peak Surge (Non-Repetitive)●●	I_{FSM}	70▲▲	70▲▲	30 ▲▲	A
Peak (Repetitive)	I_{FRM}	6.5	6	0.5	A
TEMPERATURE RANGE					
Storage	T_{stg}		−30 to 150		°C
Operating (Case)	T_C		−30 to 80		°C
LEAD TEMPERATURE (During Soldering):					
Measured 1/8 in. (3.17 mm) from case for 10 s maximum	T_L		225		°C

** For ambient temperatures up to 45°C.

●● For a maximum of 3 pulses, each less than 10 μs duration, during any 64-μs period.

■■ Maximum current rating applies only if the rectifier is properly mounted to maintain junction temperature below 150°C.

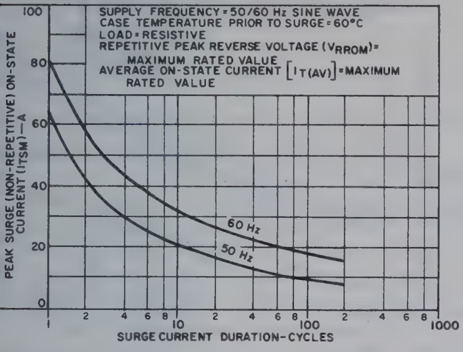
▲▲ See Fig.9 for I_{FSM} value for 50 and 60 Hz operation.

SILICON RECTIFIERS

ELECTRICAL CHARACTERISTICS

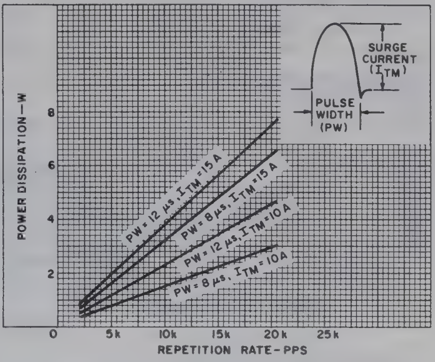
CHARACTERISTIC	SYMBOL	LIMITS		UNITS
		D2601M TRACE D2601E COMMUT.	D2600M CLAMP	
		MAXIMUM	MAXIMUM	
Reverse Current: *Static* For V_{RRM} = max. rated value, $I_F = 0$, $T_C = 25°C$ For $V_R = 500$ V, $T_C = 100°C$	I_{RM}	10 250	10 250	μA
Instantaneous Forward Voltage Drop: At $i_F = 4$ A, $T_A = 25°C$	v_F	1.9	2	V
Reverse Recovery Time: For circuit shown in Fig. 8: At $I_{FM} = 20$ A, $-di_F/dt = -20$ A/μs, pulse duration = 2.8 μs, $T_C = 25°C$	t_{rr}	0.5	0.7	μs
In Tektronix type "S" plug-in unit (or equivalent): At $I_F = 20$ mA, $I_R = 1$ mA, $T_C = 25°C$		1.2	1.5	
Peak Forward Voltage Drop (at turn-on): In Tektronic type "S" plug-in unit (or equivalent): At $I_F = 20$ mA, $T_C = 25°C$	$V_{F(pk)}$	5	6	V
Thermal Resistance (Junction-to-Lead)♦ (See Fig.14)	$R_{\theta JL}$	45	45	°C/W

♦ Measured on anode lead 1/8 in. (3.18 mm) from case.



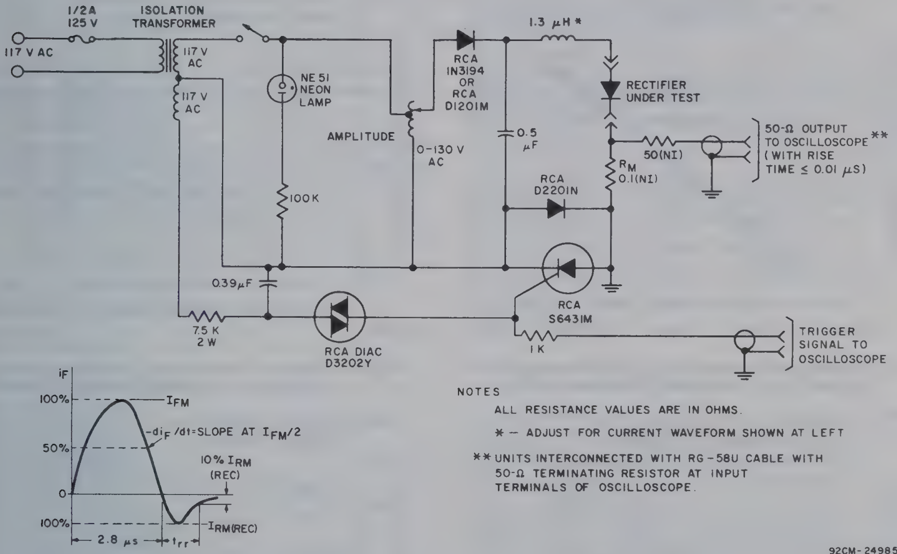
92LS-1149R2

Fig.6 — Peak surge on-state current vs. surge current duration for S3705M and S3706E.



92CS-24983

Fig.7 — Dissipation vs. repetition rate for S3705M and S3706E.


1/2 A 125 V
ISOLATION TRANSFORMER
117 V AC
117 V AC
117 V AC
NE 51 NEON LAMP
AMPLITUDE
0-130 V AC
100 K
0.39 µF
7.5 K 2 W
RCA DIAC D3202Y
RCA 1N3194 OR RCA D1201M
0.5 µF
1.3 µH *
RECTIFIER UNDER TEST
RCA D2201N
R_M 0.1 (NI)
50 (NI)
50-Ω OUTPUT TO OSCILLOSCOPE ** (WITH RISE TIME ≤ 0.01 µS)
RCA S6431M
1 K
TRIGGER SIGNAL TO OSCILLOSCOPE
i_F
100%
50%
0
100%
I_{FM}
$-di_F/dt$ = SLOPE AT $I_{FM}/2$
10% I_{RM} (REC)
$I_{RM(REC)}$
2.8 µs
t_{rr}

NOTES

ALL RESISTANCE VALUES ARE IN OHMS.

* — ADJUST FOR CURRENT WAVEFORM SHOWN AT LEFT

** UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE.

92CM-24985

Fig. 8 — Oscilloscope display and test circuit for measurement of reverse-recovery time for D2600M, D2601E, and D2601M.

TERMINAL CONNECTIONS FOR TYPES S3705M AND S3706E

Pin 1 — Gate
Pin 2 — Cathode
Case, Mounting Flange — Anode

TERMINAL CONNECTIONS FOR TYPES D2600M, D2601E, AND D2601M

Case, Lead 1 — Cathode
Lead 2 — Anode

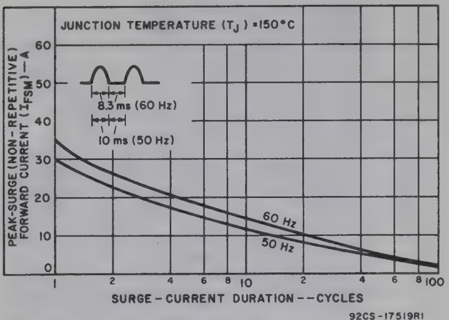


Fig.9 — Peak-surge (non-repetitive) forward current vs. surge-current duration for D2600M, D2601E, and D2601M.

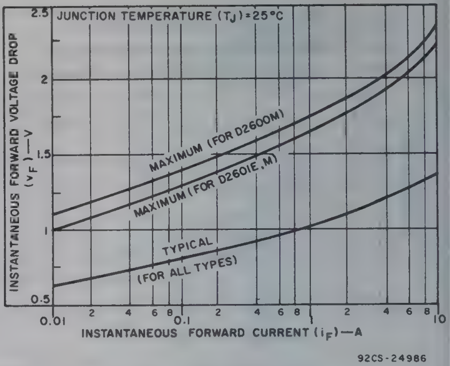


Fig.10 — Forward-voltage drop vs. forward current for D2600M, D2601E, and D2601M.

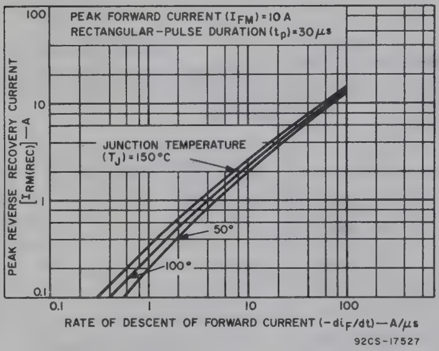


Fig.11 — Typical peak reverse-recovery current vs. rate of descent of forward current for D2600M, D2601E, and D2601M.

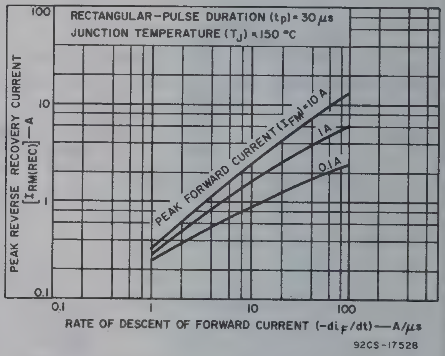


Fig.12 — Typical peak reverse-recovery current vs. rate of descent of forward-current for D2600M, D2601E, and D2601M.

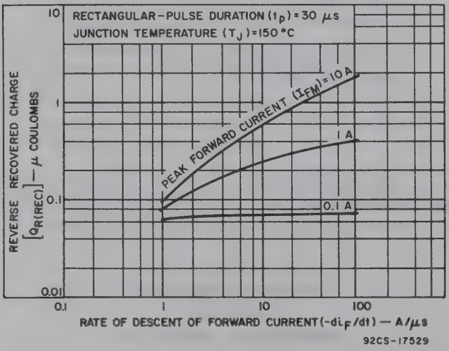


Fig.13 — Typical reverse-recovered charge vs. rate of descent of forward current for D2600M, D2601E, and D2601M.

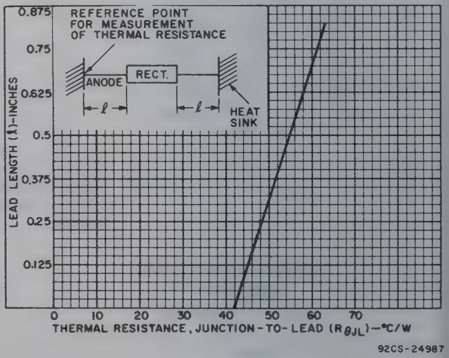
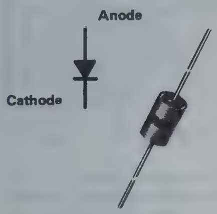


Fig.14 — Junction-to-lead thermal resistance vs. lead length for D2600M, D2601E, and D2601M.

RCA
Solid State Division

Rectifiers

D2601 Series



JEDEC DO-26

1-A, 50-to-800-V Fast-Recovery Silicon Rectifiers

General-Purpose Types for Medium-Current Applications

Features:

- Fast reverse-recovery time (t_{rr}) — 0.5 μs max. (I_{FM} = 20 A peak see test circuit Fig. 13)
  0.2 μs max. (I_F = 1 A, I_{RM} = 2 A max., see test circuit Fig. 14)
- Low overshoot current
- Low forward-voltage drop
- Low-thermal-resistance hermetic package

Voltage / Package	50 V	100 V	200 V	400 V	600 V	800 V
DO-26	D2601F –	D2601A –	D2601B (TA7892)	D2601D (TA7893)	D2601M (TA7894)	D2601N (TA7895)

Numbers in parentheses (e.g. TA7892) are former RCA-Dev. Type numbers

RCA-D2601-series rectifiers are silicon diffused-junction-types in an axial-lead hermetic package. They differ only in their voltage ratings.

These devices feature fast recovery times (0.5 μs max. from 20 A peak) without the "snap" type of turn-off which could result in the generation of transients.

Types D2601A, B, D, F, M, and N are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications.

MAXIMUM RTAINGS, *Absolute-Maximum Values:*

		D2601F	D2601A	D2601B	D2601D	D2601M	D2601N	
REVERSE VOLTAGE:								
REPETITIVE PEAK	V_{RRM}	50	100	200	400	600	800	V
NON-REPETITIVE PEAK	V_{RSM}	100	200	300	500	700	1000	V
FORWARD CURRENT:•								
Conduction angle = 180°, half-sine-wave								
RMS	$I_{F(RMS)}$	1.5						A
Average	I_o	1						A
PEAK-SURGE (NON-REPETITIVE) CURRENT:								
At junction temperature (T_J) = 150°C								
For one-half cycle of applied voltage, 60 Hz (8.3 ms)		35						A
For other durations		See Fig. 2						
PEAK (REPETITIVE) CURRENT	I_{FRM}	6						A
TEMPERATURE RANGE:								
Storage	T_{stg}	−40 to 165						°C
Operating (Junction)	T_J	−40 to 150						°C
LEAD TEMPERATURE (During Soldering):	T_L							
At a distance of 1/8 in. (3.17 mm) from case for 10 s max.		225						°C

• At lead temperature of 100°C (measured at point of anode lead 1/8 in. (3.17 mm) from the case).

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS ALL TYPES MIN.	 MAX.	UNITS
Reverse Current:				
Static				
For V_{RRM} = max. rated value, I_F = 0, T_J = 25°C	I_{RM}	–	15	μA
T_J = 100°C		–	250	
Dynamic		See Fig. 9		
Instantaneous Forward Voltage Drop: At i_F = 4 A, T_J = 25°C (See Fig. 3)	v_F	–	1.9	V
Reverse Recovery Time: For circuit shown in Fig. 13, at I_{FM} = 20 A, $-di_F/dt$ = –20 A/μs, plus duration = 2.8 μs, T_C = 25°C	t_{rr}	–	0.5	μs
For circuit shown in Fig. 14, at I_F = 1 A, I_{RM} = 2 max., T_C = 25°C		–	0.2	
Thermal Resistance (Junction-to-Lead)■	$R_{\theta JL}$	–	45	°C/W

■ Measured at point on anode lead 1/8 in. (3.17 mm) from case

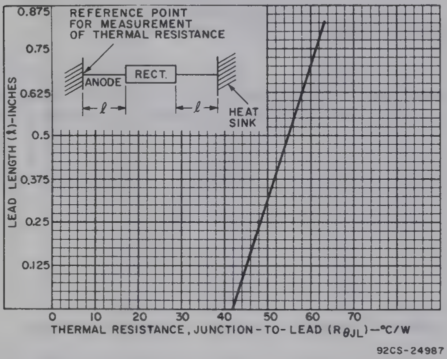


Fig. 1 — Average forward-power dissipation vs. lead temperature.

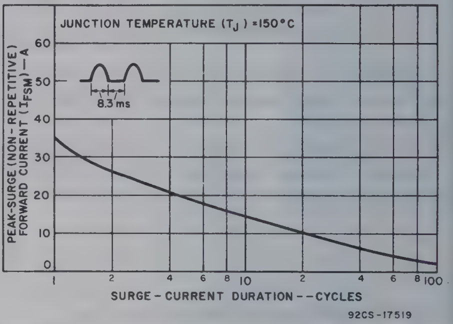


Fig. 2 — Peak-surge (non-repetitive) forward current vs. surge-current duration.

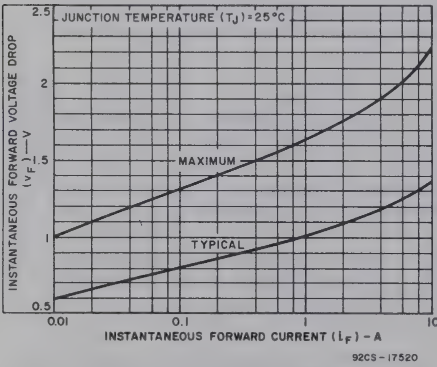


Fig. 3 — Forward-voltage drop vs. forward current.

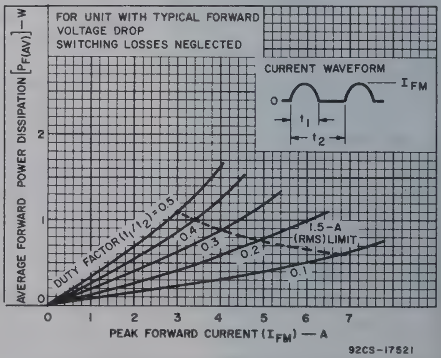


Fig. 4 — Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.

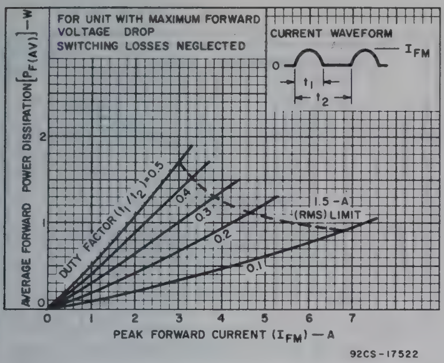


Fig. 5 — Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.

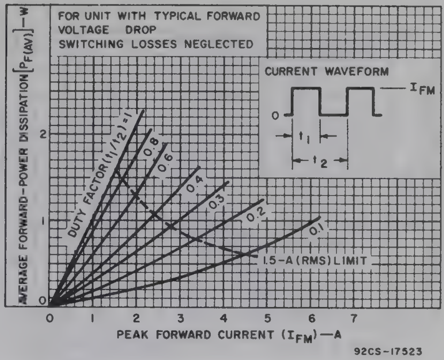


Fig. 6 — Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.

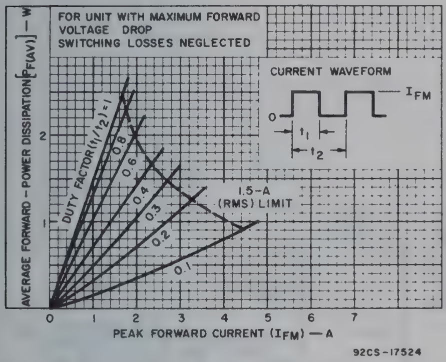


Fig. 7 — Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.

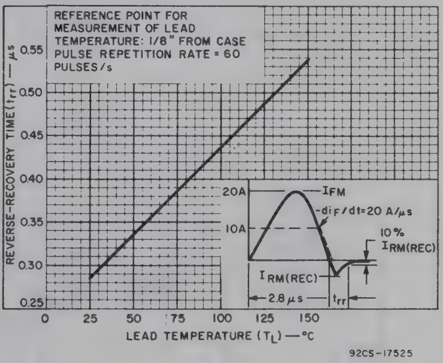


Fig. 8 — Typical variation of reverse-recovery time with lead temperature.

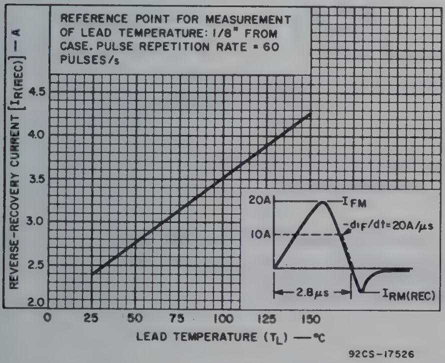


Fig. 9 — Reverse-recovery current vs. lead temperature.

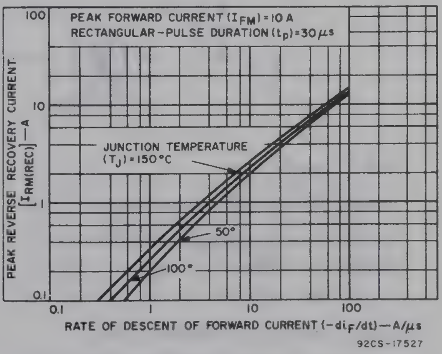


Fig. 10 — Peak reverse-recovery current vs. rate of descent of forward current.

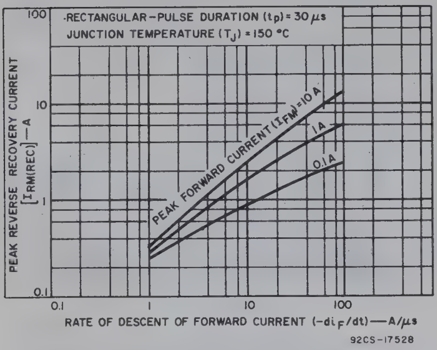


Fig. 11 — Peak reverse-recovery current vs. rate of descent of forward current.

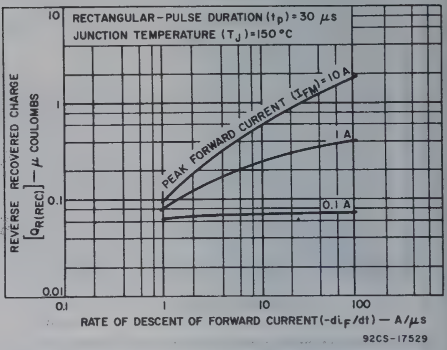
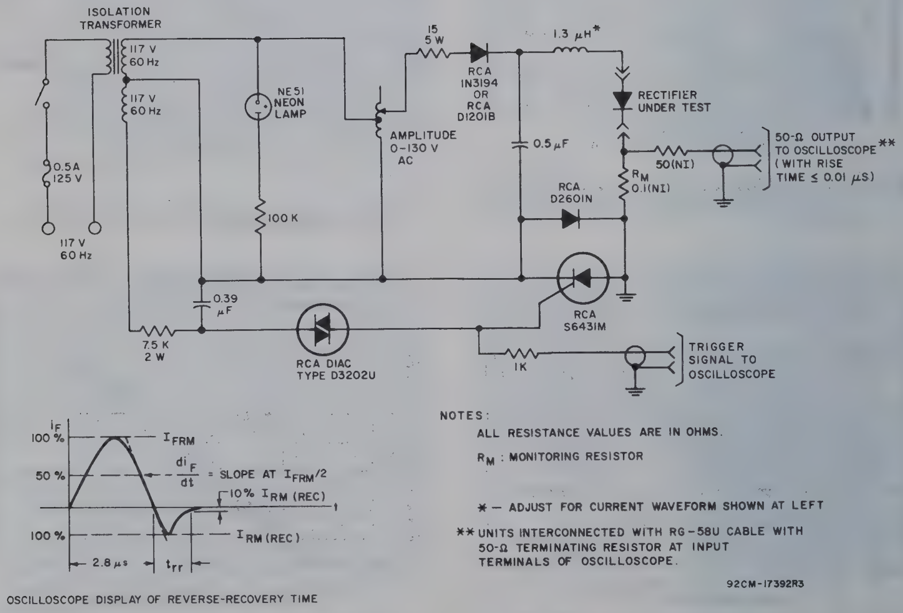


Fig. 12 — Reverse-recovered charge vs. rate of descent of forward current.


ISOLATION TRANSFORMER
117 V 60 Hz
117 V 60 Hz
0.5 A 125 V
117 V 60 Hz
NE51 NEON LAMP
100 K
15 5 W
RCA 1N3194 OR RCA D1201B
AMPLITUDE 0-130 V AC
1.3 μH*
RECTIFIER UNDER TEST
0.5 μF
50-Ω OUTPUT TO OSCILLOSCOPE** (WITH RISE TIME ≤ 0.01 μS)
50(NI)
R_M 0.1(NI)
RCA D2601N
RCA S6431M
0.39 μF
7.5 K 2 W
RCA DIAC TYPE D3202U
1K
TRIGGER SIGNAL TO OSCILLOSCOPE
i_F
100 %
50 %
100 %
I_{FRM}
$\frac{di_F}{dt}$ = SLOPE AT $I_{FRM}/2$
10% I_{RM} (REC)
I_{RM} (REC)
2.8 μs
t_{rr}
OSCILLOSCOPE DISPLAY OF REVERSE-RECOVERY TIME

NOTES:

ALL RESISTANCE VALUES ARE IN OHMS.

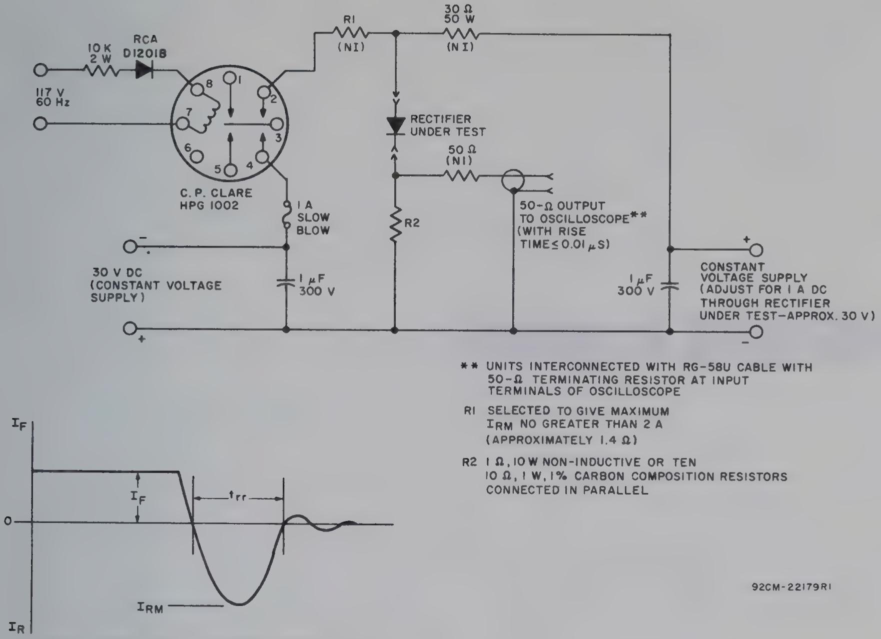
R_M : MONITORING RESISTOR

* — ADJUST FOR CURRENT WAVEFORM SHOWN AT LEFT

** UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE.

92CM-17392R3

Fig. 13 — Test circuit (pulsed sine wave) for measurement of reverse-recovery time.


117 V
60 Hz
10 K
2 W
RCA
D1201B
C. P. CLARE
HPG 1002
1
2
3
4
5
6
7
8
R1
(NI)
30 Ω
50 W
(NI)
RECTIFIER
UNDER TEST
50 Ω
(NI)
50-Ω OUTPUT
TO OSCILLOSCOPE**
(WITH RISE
TIME ≤ 0.01 μS)
R2
1 A
SLOW
BLOW
30 V DC
(CONSTANT VOLTAGE
SUPPLY)
1 μF
300 V
1 μF
300 V
CONSTANT
VOLTAGE SUPPLY
(ADJUST FOR 1 A DC
THROUGH RECTIFIER
UNDER TEST–APPROX. 30 V)
+
−
I_F
I_F
0
t_{rr}
I_{RM}
I_R
92CM-22179R1

** UNITS INTERCONNECTED WITH RG-58U CABLE WITH 50-Ω TERMINATING RESISTOR AT INPUT TERMINALS OF OSCILLOSCOPE

R1 SELECTED TO GIVE MAXIMUM I_{RM} NO GREATER THAN 2 A (APPROXIMATELY 1.4 Ω)

R2 1 Ω, 10 W NON-INDUCTIVE OR TEN 10 Ω, 1 W, 1% CARBON COMPOSITION RESISTORS CONNECTED IN PARALLEL

OSCILLOSCOPE DISPLAY OF REVERSE-RECOVERY TIME

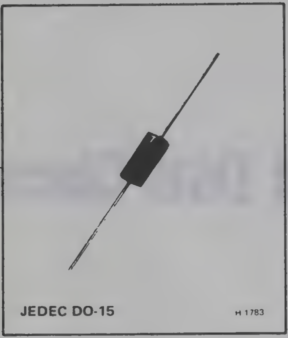
Fig. 14 — Test circuit (pulsed dc) for measurement of reverse-recovery time.

Technical Data-Diacs

RCA
Solid State
Division

Thyristors

D3202Y
D3202U


JEDEC DO-15

Silicon Bidirectional Diacs

Plastic-Packaged Two-Terminal Trigger Devices for Applications in Military, Industrial, and Commercial Equipment

Features:

- **For critical triggering applications requiring narrow breakover voltage range (29-35V)—D3202Y**
- **Typical breakover voltage: $V_{(BO)} = 32$ V**
- **Low breakover current (at breakover voltage): $I_{(BO)} = 25\ \mu A$ max.**
- **High peak pulse current capability**
- **Breakover voltage symmetry:** $\left|+V_{(BO)}\right| - \left|-V_{(BO)}\right| = \pm 3$ V max.

RCA D3202Y (45411)* and D3202U (45412)* are all-diffused, three-layer, two-terminal devices in an axial-lead plastic package designed specifically for triggering thyristors. Both units exhibit bidirectional negative-resistance characteristics.

These diacs are intended for use in thyristor phase-control circuits for lamp-dimming, universal-motor speed control, and heat controls. Their small size and plastic package of high insulation resistance make these diacs especially suitable for applications in which high packing densities are employed.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

DEVICE DISSIPATION:

At case temperature up to 40°C	1 W
At case temperatures above 40°C	Derate 0.016 W/°C

TEMPERATURE RANGE:

Storage	−40 to +150 °C
Operating (Junction)	−40 to +100 °C

LEAD TEMPERATURE (During Soldering)

At distance ≥ 1/16 in. (1.59 mm) from case for 10 s max.	240 °C

---

*Number in parentheses is a former RCA type number.

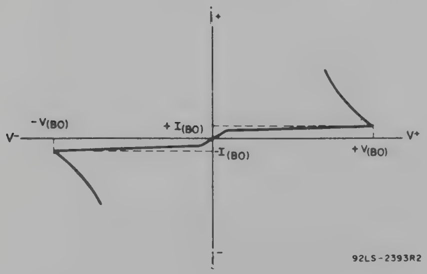


Fig.1—Voltage-current characteristic for both types.

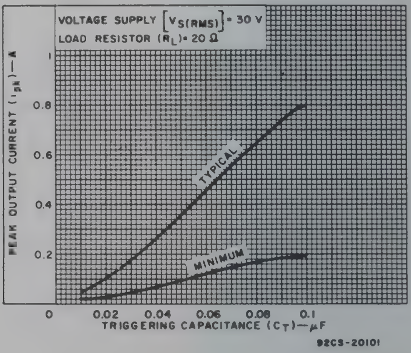


Fig.2—Peak output current vs. triggering capacitance.

ELECTRICAL CHARACTERISTICS: At Case Temperature (T_C) = 25°C

CHARACTERISTIC	SYMBOL	TEST CONDITIONS	LIMITS				UNITS
			D3202Y		D3202U		
			MIN.	MAX.	MIN.	MAX.	
Breakover Voltage (Forward or Reverse)	$V_{(BO)}$		29	35	25	40	V
Breakover Voltage Symmetry	$\left\|+V_{(BO)}\right\| - \left\|-V_{(BO)}\right\|$		–	±3	–	±3	V
Peak Output Current (See Figs. 2, 3, & 5.)	i_{pk}	V_{SUPPLY} = 30 V_{RMS}, C_T = 0.1 μF, R_L = 20 Ω	190	–	190	–	mA
Peak Breakover Current	$I_{(BO)}$	At breakover voltage	–	25	–	25	μA
Dynamic Breakback Voltage	$\|\Delta V\pm\|$	V_{SUPPLY} = 30 V_{RMS}, C_T = 0.1 μF R_L = 20 Ω	9	–	9	–	V
Thermal Impedance Junction-to-ambient	$I_{\theta JA}$		–	60	–	60	°C/W

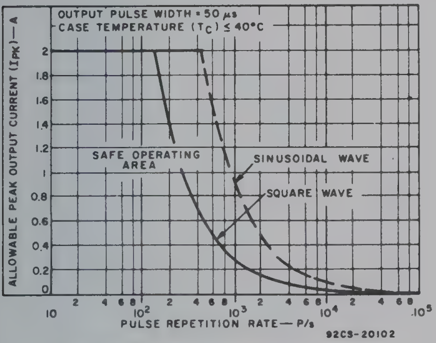


Fig.3—Peak output-current derating curves.

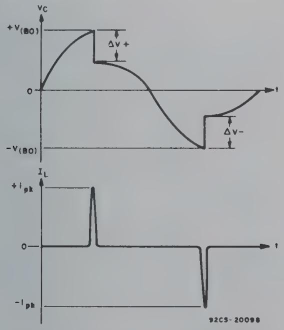
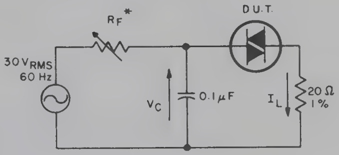


Fig.5—Test circuit waveforms (see Fig.4).



*ADJUST FOR ONE FIRING IN HALF CYCLE
D.U.T.=DIAC UNDER TEST

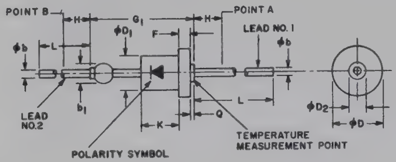
92CS-20100

Fig.4—Circuit used to measure diac characteristics.

Dimensional Outlines and Suggested Mounting Hardware

Dimensional Outlines for Thyristors and Rectifiers

DO-1

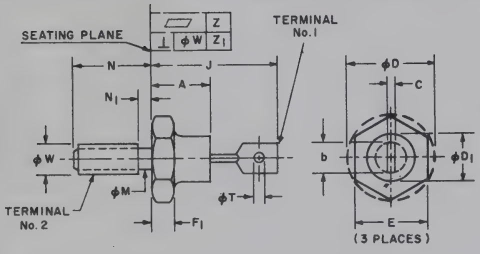

POINT B
H
G_1
H
POINT A
ϕD_1
F
LEAD NO. 1
ϕb
L
ϕb
LEAD NO.2
b_1
L
Q
ϕD_2
ϕD
K
TEMPERATURE MEASUREMENT POINT
POLARITY SYMBOL
92CS-17423R1

SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
ϕb	0.027	0.035	0.69	0.89	2
b_1	–	0.125	–	3.18	1
ϕD	0.360	0.400	9.14	10.16	
ϕD_1	0.245	0.280	6.22	7.11	
ϕD_2	–	0.200	–	5.08	
F	–	0.075	–	1.91	
G_1	–	0.725	–	18.42	
H	0.5	–	12.7	–	
K	0.220	0.260	5.59	6.60	
L	1.000	1.625	25.40	41.28	
Q	–	0.025	–	0.64	

NOTES:

1. Dimensions to allow for pinch or seal deformation anywhere along tubulation (optional).
2. Diameter to be controlled from free end of lead to within 0.188 inch (4.78 mm) from the point of attachment to the body. Within the 0.188 inch (4.78 mm) dimension, the diameter may vary to allow for lead finishes and irregularities.

DO-4


SEATING PLANE
Z
$\perp$ ϕW Z_1
TERMINAL No. 1
N
J
A
N_1
ϕW
ϕM
ϕT
TERMINAL No. 2
F_1
ϕD
C
b
ϕD_1
E
(3 PLACES)
92CS-20472

SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.405	–	10.28	
b	–	0.250	–	6.35	2
c	0.020	0.065	0.51	1.65	
ϕD	–	0.505	–	12.82	
ϕD_1	0.265	0.424	6.74	10.76	
E	0.423	0.438	10.75	11.12	
F_1	0.075	0.175	1.91	4.44	1
J	0.600	0.800	15.24	20.32	
ϕM	0.163	0.189	4.15	4.80	
N	0.422	0.453	10.72	11.50	
N_1	–	0.078	–	1.98	
ϕT	0.060	0.095	1.53	2.41	
ϕW	10-32 UNF-2A		10-32 UNF-2A		3
Z	–	0.002	–	0.050	
Z_1	–	0.006	–	0.152	

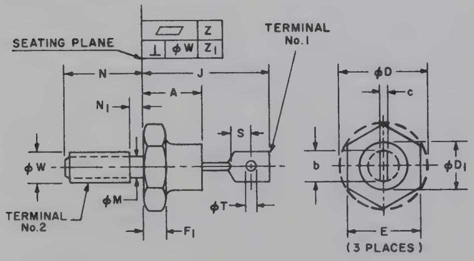
NOTES:

1: Chamfer or undercut on one or both sides of hexagonal base is optional.

2: Angular orientation and contour of Terminal No. 1 is optional.

3: ϕW is pitch diameter of coated threads. REF: Screw Thread Standards for Federal Services, Handbook H 28 Part I. Recommended torque: 15 inch-pounds.

DO-5

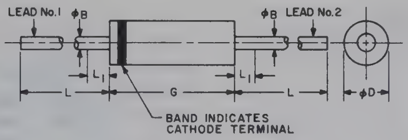

SEATING PLANE
Z
$\perp$ ϕW Z_1
TERMINAL No. 1
N
J
A
N_1
S
ϕW
ϕM
ϕT
TERMINAL No.2
F_1
ϕD
c
b
ϕD_1
E
(3 PLACES)
92CS-20473R1

SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.450	–	11.43	
b	–	0.375	–	9.52	
c	0.030	0.080	0.77	2.03	
ϕD	–	0.794	–	20.16	
ϕD_1	–	0.667	–	16.94	
E	0.669	0.688	17.00	17.47	
F_1	0.115	0.200	2.93	5.08	
J	0.750	1.000	19.05	25.40	
ϕM	0.220	0.249	5.59	6.32	
N	0.422	0.453	10.72	11.50	
N_1	–	0.090	–	2.28	
S	0.156	–	3.97	–	
ϕT	0.140	0.175	3.56	4.44	
ϕW	1/4-28 UNF 2A		1/4-28 UNF 2A		1
Z	–	0.002	–	0.050	
Z_1	–	0.006	–	0.152	

NOTE

1: ϕW is pitch diameter of coated threads. REF: Screw-Thread Standards for Federal Services, Handbook H 28 Part I. Recommended torque: 30 inch-pounds.

DO-15

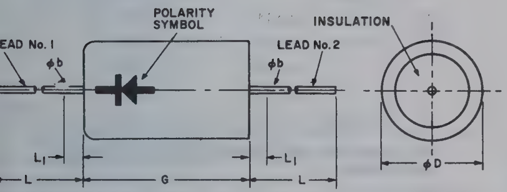

LEAD No.1
ϕB
ϕB
LEAD No.2
L_1
L_1
L
G
L
ϕD
BAND INDICATES CATHODE TERMINAL

92CS-17313R1

SYMBOL	INCHES		MILLIMETERS	
	MIN.	MAX.	MIN.	MAX.
ϕb	0.027	0.035	0.686	0.889
ϕD	0.104	0.140	2.64	3.56
G	0.230	0.300	5.84	7.62
L	1.000	–	25.40	–
L_1*	–	0.050	–	1.27

*Within this zone the diameter may vary to allow for lead finishes and irregularities.

DO-26


POLARITY SYMBOL
INSULATION
EAD No. I
ϕb
LEAD No. 2
ϕb
L_1
L_1
L
G
L
ϕD

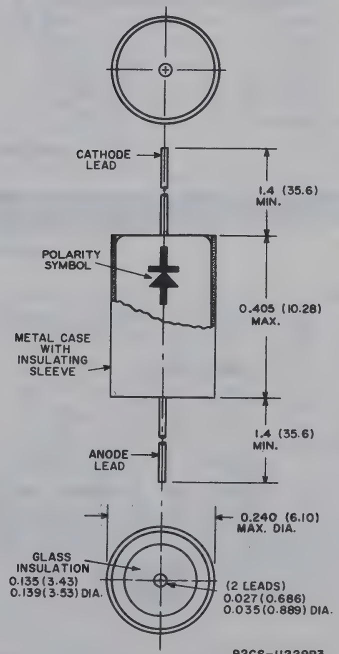
92CS-10920R6

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
ϕb	0.027	0.039	0.69	0.99	
ϕD	0.220	0.260	5.59	6.60	1
G	0.344	0.410	8.74	10.41	1
L	1.400	–	35.56	–	
L_1	–	0.080	–	2.03	2

NOTES:

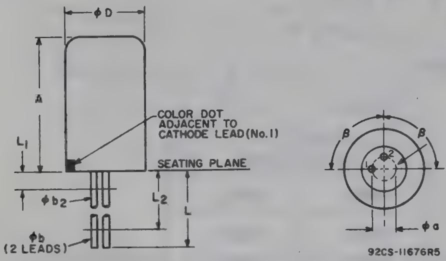
1. Package contour optional within cylinder of diameter, ϕD, and length, G. Slugs, if any, shall be included within this cylinder but shall not be subject to the minimum limit of ϕD.
2. Lead diameter not controlled in this zone to allow for flash, lead-finish build up, and minor irregularities other than slugs.

DO-26 With Insulating Sleeve


CATHODE LEAD
1.4 (35.6) MIN.
POLARITY SYMBOL
0.405 (10.28) MAX.
METAL CASE WITH INSULATING SLEEVE
1.4 (35.6) MIN.
ANODE LEAD
0.240 (6.10) MAX. DIA.
GLASS INSULATION
0.135 (3.43)
0.139 (3.53) DIA.
(2 LEADS)
0.027 (0.686)
0.035 (0.889) DIA.

92CS-11229R3

Mod. TO-1 2-Lead


ϕD
A
L1
COLOR DOT ADJACENT TO CATHODE LEAD (No.1)
SEATING PLANE
ϕb2
L2
L
ϕb (2 LEADS)
β
β
1
2
ϕa

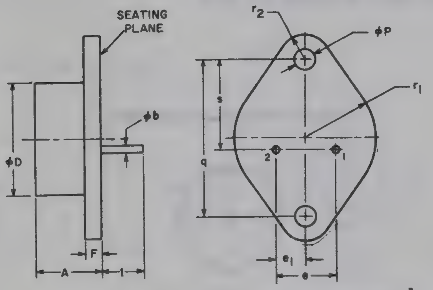
92CS-11676R5

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
ϕa	0.061	0.081	1.55	2.06	
A	–	0.410	–	10.41	
ϕb	–	0.021	–	0.533	1
ϕb2	0.016	0.019	0.406	0.483	1
ϕD	–	0.240	–	6.10	
L	1.500	–	38.10	–	
L1	–	0.05	–	1.27	1
L2	0.25	–	6.35	–	1
β	90° NOMINAL				

NOTE:

1. ϕb_2 applies between L_1 and L_2. ϕb applies between L_2 and 1.5 in. (38.10 mm) from seating plane. Diameter is uncontrolled in L_1 and beyond 1.5 in. (38.10 mm) from seating plane.

TO-3


SEATING PLANE
ϕb
ϕD
F
A
l
r2
ϕP
r1
s
q
2
1
e1
e

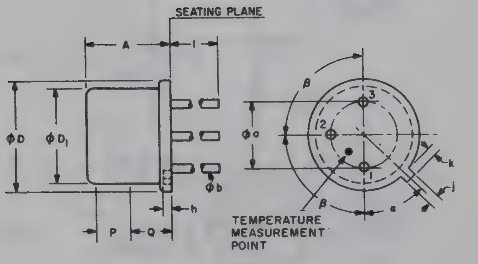
92CS–15222

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.250	0.450	6.35	11.43	
ϕb	0.038	0.043	0.97	1.09	2
ϕD		0.875		22.23	
e	0.420	0.440	10.67	11.18	
e1	0.205	0.225	5.21	5.72	
F		0.135		3.43	
1	0.312		7.92		2
ϕP	0.151	0.161	3.84	4.09	
q	1.177	1.197	29.90	30.40	
r1		0.525		13.34	
r2		0.188		4.78	
s	0.655	0.675	16.64	17.15	1

NOTES:

1. These dimensions should be measured at points 0.050 in. (1.27 mm) to 0.055 in. (1.40 mm) below seating plane. When gage is not used, measurement will be made at seating plane.
2. Two pins.

Mod. TO-5

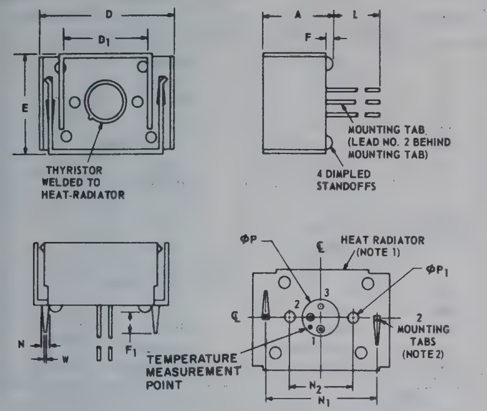

SEATING PLANE
A
l
ϕD
ϕD1
ϕb
h
P
Q
β
3
2
1
ϕa
k
j
β
a
TEMPERATURE MEASUREMENT POINT

92LM-2048R2

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
ϕa	.190	.210	4.83	5.33	
A	.240	.260	6.10	6.60	
ϕb	.017	.021	.44	.53	
ϕD	.335	.366	8.51	9.30	
ϕD1		.330	8.13	8.38	
h	.015	.035	.38	.89	
i	.028	.035	.71	.89	
k	.029	.045	.74	1.14	
l	.975	1.025	24.76	26.03	
P	.100	-	2.54	-	
Q	-	-	-	-	1
α	45° NOMINAL				
β	50° NOMINAL				

Note 1: Details of outline in this zone optional.

Mod. TO-5" with Heat Radiator


D
D1
E
THYRISTOR
WELDED TO
HEAT-RADIATOR
A
L
F
MOUNTING TAB
(LEAD NO. 2 BEHIND
MOUNTING TAB)
4 DIMPLED
STANDOFFS
N
W
F1
ΦP
℄
HEAT RADIATOR
(NOTE 1)
ΦP1
2
3
1
℄
2
MOUNTING
TABS
(NOTE 2)
TEMPERATURE
MEASUREMENT
POINT
N2
N1

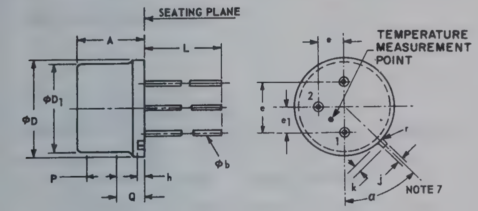
SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	.630	–	16.00	
D	1.205	1.235	30.61	31.37	
D_1	.745	.755	18.923	19.177	
E	.875	.905	22.22	22.99	
F	.040	.055	1.02	1.40	
F_1	.170	.225	4.32	5.72	
L	.920	–	23.37	–	
ΦP	.295	.305	7.493	7.747	
$ΦP_1$	.093	.095	2.362	2.413	
N	.048	.062	1.21	1.57	
N_1	.998	1.002	25.349	25.450	3
N_2	.687	.689	17.45	17.50	3
W	.048	.052	1.219	1.320	

92LM-2109R1

NOTES:

1. 0.035 C.R.S., finish: electroless nickel plate
2. Recommended hole size for printed-circuit board is 0.070 in. (1.78 mm) dia.
3. Measured at bottom of heat radiator

"Low-Profile TO-5"


SEATING PLANE
A
L
ΦD1
ΦD
Φb
P
h
Q
TEMPERATURE
MEASUREMENT
POINT
e
e1
2
1
r
j
k
α
NOTE 7

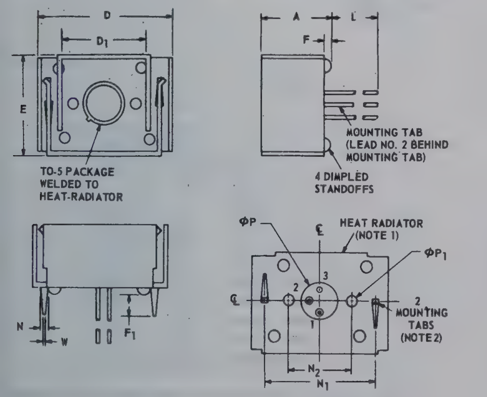
SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	.160	.180	4.06	4.57	
Φb	.017	.021	.432	.533	2
ΦD	.355	.366	9.017	9.296	
$ΦD_1$	.323	.335	8.204	8.51	
e	.190	.210	4.83	5.33	
e_1	.100 TRUE POSITION		2.54 TRUE POSITION		4,5
h	.015	.035	.381	.889	
j	.028	.035	.711	.889	5
k	.029	.045	.737	1.14	3,5
L	.985	1.015	25.02	25.78	2
P	.100		2.54		1
Q					6
r		.007		.179	
α	42°	48°			5,7

NOTES:

1. This zone is controlled for automatic handling. The variation in actual diameter within the zone shall not exceed .012 in. (.279 mm).
2. (Three Leads) ϕ b applies between seating plane and 1.015 in. (25.78 mm).
3. Measured from maximum diameter of the actual device.
4. Leads having maximum diameter .021 in. (.533 mm) measured at the seating plane of the device shall be within .007 in. (.178 mm) of their true positions relative to the maximum-width tab.
5. The device may be measured by direct methods or by the gage and gaging procedure described on gage drawing GS-1 of JEDEC publication 12E, May 1964.
6. Details of outline in this zone optional.
7. Tab centerline.

92SS-3901R1

"Low-Profile TO-5" with Heat Radiator


D
D1
E
TO-5 PACKAGE
WELDED TO
HEAT-RADIATOR
A
L
F
MOUNTING TAB
(LEAD NO. 2 BEHIND
MOUNTING TAB)
4 DIMPLED
STANDOFFS
N
W
F1
ΦP
℄
HEAT RADIATOR
(NOTE 1)
ΦP1
2
3
1
℄
2
MOUNTING
TABS
(NOTE 2)
N2
N1

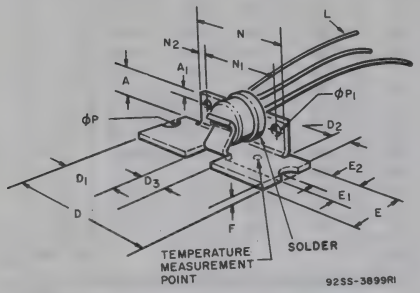
SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	.630	–	16.00	
D	1.205	1.235	30.61	31.37	
D_1	.745	.755	18.923	19.177	
E	.875	.905	22.22	22.99	
F	.040	.055	1.02	1.40	
F_1	.170	.225	4.32	5.72	
L	.885	–	22.48	–	
ΦP	.295	.305	7.493	7.747	
$ΦP_1$	.093	.095	2.362	2.413	
N	.048	.062	1.21	1.57	
N_1	.998	1.002	25.349	25.450	3
N_2	.687	.689	17.45	17.50	3
W	.048	.052	1.219	1.320	

NOTES:

1. 0.035 C.R.S., finish: electroless nickel plate
2. Recommended hole size for printed-circuit board is 0.070 in. (1.78 mm) dia.
3. Measured at bottom of heat-radiator

92SS-3900R1

"Low-Profile TO-5" with Heat Spreader

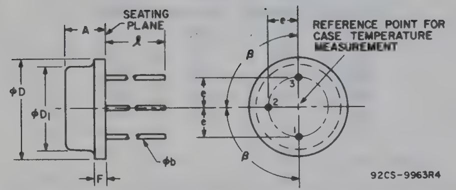

L
N
N2
N1
A1
A
ϕP
ϕP1
D2
E2
E1
E
D1
D3
D
F
TEMPERATURE MEASUREMENT POINT
SOLDER
92SS-3899R1

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.22		5.58		
A_1	0.75		19.05		
D	1.0		25.4		
D_1	0.406		10.31		
D_2	0.14	0.16	3.55	4.06	
D_3	0.188		4.77		
E	0.40		10.16		
E_1	0.32		8.12		
E_2	0.156		3.96		
F	0.02		0.05		
L	0.95	—	24.13	–	1
N	0.69	0.71	17.52	18.03	
N_1	0.55		13.97		
N_2	0.75		19.05		
ϕP	0.072 Rad.		1.83 Rad.		
ϕP_1	0.094 Dia.		2.39 Dia.		2

NOTES:

1. Min. length, 3 leads.
2. Two holes.

TO-8

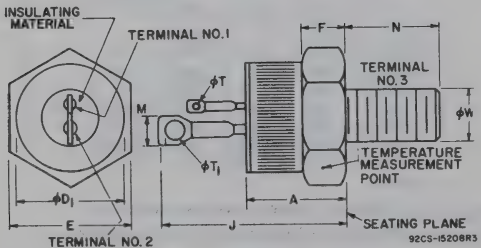

A
SEATING PLANE
ℓ
e
REFERENCE POINT FOR CASE TEMPERATURE MEASUREMENT
β
ϕD
ϕD1
e
e
3
2
1
ϕb
β
F
92CS-9963R4

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.270	0.330	6.86	8.38	–
ϕb	0.027	0.033	0.686	0.838	1
ϕD	0.550	0.650	13.97	16.51	–
ϕD_1	0.444	0.524	11.28	13.31	–
e	0.136	0.146	3.45	3.71	–
F	–	0.115	–	2.92	–
ℓ	0.360	0.440	9.14	11.18	1
β	90° NOMINAL				

NOTE:

1. Three leads.

TO-48


INSULATING MATERIAL
TERMINAL NO.1
ϕT
M
ϕT1
ϕD1
E
TERMINAL NO. 2
F
N
TERMINAL NO. 3
ϕW
TEMPERATURE MEASUREMENT POINT
A
J
SEATING PLANE
92CS-15208R3

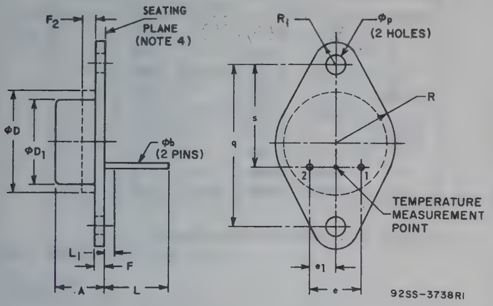
SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.330	0.505	8.4	12.8	–
ϕD_1	–	0.544	–	13.81	–
E	0.544	0.562	13.82	14.28	–
F	0.113	0.200	2.87	5.08	–
J	0.950	1.100	24.13	27.94	–
M	0.215	0.225	5.46	5.71	–
N	0.422	0.453	10.72	11.50	–
ϕT	0.058	0.068	1.47	1.73	–
ϕT_1	0.138	0.148	3.51	3.75	–
ϕW	1/4-28 UNF-2A		1/4-28 UNF-2A		1

NOTE

1. ϕW is pitch diameter of coated threads.

REF: Screw-Thread Standards for Federal Services, Handbook H28, Part I. Recommended Torque: 25 inch-pounds.

TO-66

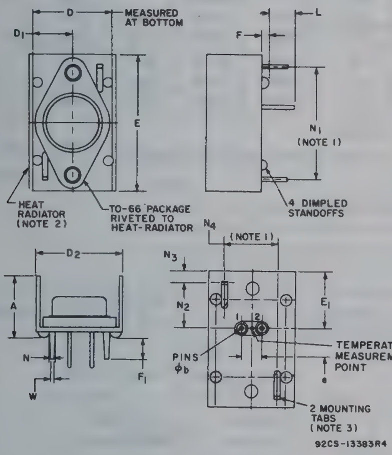

F2
SEATING PLANE (NOTE 4)
R1
φp (2 HOLES)
R
φD
φD1
φb (2 PINS)
s
q
2
1
TEMPERATURE MEASUREMENT POINT
L1
F
A
L
e1
e
92SS-3738RI

SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	0.250	0.340	6.35	8.64	
φb	0.028	0.034	0.711	0.863	
φD	–	0.620	–	15.75	1
φD1	0.470	0.500	11.94	12.70	
e	0.190	0.210	4.83	5.33	2
e1	0.093	0.107	2.36	2.72	2
F1	0.050	0.075	1.27	1.91	
F2	–	0.050	–	1.27	1
L	0.360	–	9.14	–	
L1	–	0.050	–	1.27	3
φp	0.142	0.152	3.61	3.86	
q	0.958	0.962	24.33	24.43	
R	–	0.350	–	8.89	
R1	–	0.145	–	3.68	
s	0.570	0.590	14.48	14.99	

NOTES:

1. Body contour is optional within zone defined by φD and F_2.
2. These dimensions should be measured at points 0.050 in. (1.27 mm) to 0.055 in. (1.40 mm) below seating plane. When gage is not used, measurement will be made at seating plane.
3. φb applies between L_1 and L. Diameter is uncontrolled in L_1.
4. The seating plane of header shall be flat within 0.001 in. (0.025 mm) concave to 0.004 in. (0.10 mm) convex inside a 0.520 in. (13.21 mm) diameter circle on the center of the header and flat within 0.001 in (0.025 mm) concave to 0.006 in. (0.15 mm) convex overall.

TO-66 with Heat Radiator

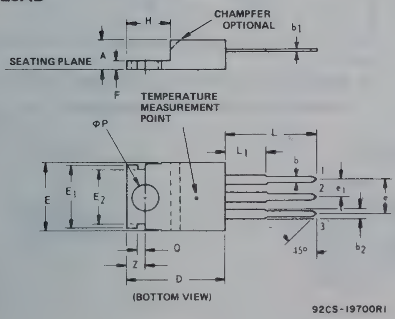

D
MEASURED AT BOTTOM
D1
E
HEAT RADIATOR (NOTE 2)
TO-66 PACKAGE RIVETED TO HEAT-RADIATOR
F
L
N1 (NOTE 1)
4 DIMPLED STANDOFFS
D2
A
N
W
F1
N4
(NOTE 1)
N3
N2
E1
1
2
PINS φb
TEMPERATURE MEASUREMENT POINT
e
2 MOUNTING TABS (NOTE 3)
92CS-13383R4

SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.620	–	15.75	
φb	0.028	0.034	0.711	0.864	
D	0.750	0.760	19.05	19.30	
D1	0.370	0.385	9.40	9.78	
D2	0.820	0.920	20.83	23.37	
E	1.297	1.327	32.94	33.70	
E1	0.546	0.566	13.87	14.37	
e	0.190	0.210	4.83	5.33	
F	0.30	0.55	7.62	13.97	
F1	0.175	0.210	4.44	5.33	
L	0.270	–	6.86	–	
N	0.052	0.065	1.32	1.65	
N1	1.098	1.102	27.89	27.99	1
N2	0.448	0.452	11.38	11.47	
N3	0.099	0.113	0.25	0.29	
N4	0.498	0.502	12.65	12.75	
W	0.048	0.060	1.22	1.52	

NOTES:

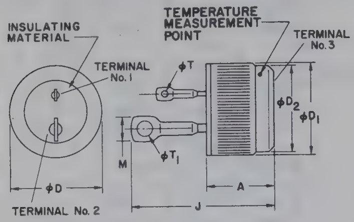
1. Measured at bottom of heat radiator.
2. 0.035 in. (0.889) C.R.S., tin plated.
3. Recommended hole size for printed-circuit board is 0.070 in. (1.778) dia.

TO-220AB


H
CHAMPFER OPTIONAL
b1
SEATING PLANE
A
F
TEMPERATURE MEASUREMENT POINT
φP
L
L1
b
1
2
3
e1
e
E
E1
E2
15°
b2
Q
Z
D
(BOTTOM VIEW)
92CS-19700RI

SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.
A	0.160	0.190	4.07	4.82
b	0.025	0.040	0.64	1.02
b1	0.012	0.020	0.31	0.51
b2	0.045	0.055	1.143	1.397
D	0.575	0.600	14.61	15.24
E	0.395	0.410	10.04	10.41
E1	0.365	0.385	9.28	9.77
E2	0.300	0.320	7.62	8.12
e	0.180	0.220	4.57	5.58
e1'	0.080	0.120	2.03	3.04
F	0.020	0.055	0.51	1.39
H	0.235	0.265	5.97	6.73
L	0.500	–	12.70	–
L1	–	0.250	–	6.35
φP	0.141	0.145	3.582	3.683
Q	0.040	0.060	1.02	1.52
Z	0.100	0.120	2.54	3.04

Press-Fit
6-, 10-, and 15-A Triacs; 20- and 35-A SCR's

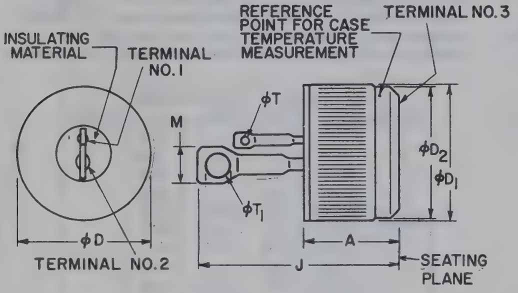

INSULATING MATERIAL
TEMPERATURE MEASUREMENT POINT
TERMINAL No. 3
TERMINAL No. 1
ϕT
ϕD_2
ϕD_1
M
ϕT_1
ϕD
A
J
TERMINAL No. 2

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.380	–	9.65	
ϕD	0.501	0.510	12.73	12.95	
ϕD_1	–	0.505	–	12.83	1
ϕD_2	0.465	0.475	11.81	12.07	
J	–	0.750	–	19.05	
M	–	0.155	–	3.94	
ϕT	0.058	0.068	1.47	1.73	
ϕT_1	0.080	0.090	2.03	2.29	

NOTE 1: Outer diameter of knurled surface.

92CS-23134

Press-Fit
25-, 30-, and 40-A Triacs


INSULATING MATERIAL
TERMINAL NO. 1
REFERENCE POINT FOR CASE TEMPERATURE MEASUREMENT
TERMINAL NO. 3
ϕT
M
ϕD_2
ϕD_1
ϕT_1
ϕD
A
TERMINAL NO. 2
J
SEATING PLANE

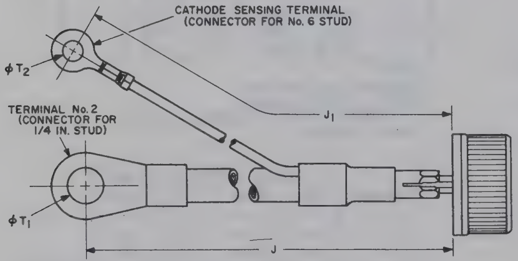
SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.380	–	9.65	–
ϕD	0.501	0.510	12.73	12.95	–
ϕD_1	–	0.505	–	12.83	1
ϕD_2	0.465	0.475	11.81	12.07	–
J	0.825	1.000	20.95	25.40	–
M	0.215	0.225	5.46	5.71	–
ϕT	0.058	0.068	1.47	1.73	–
ϕT_1	0.138	0.148	3.51	3.75	–

NOTE:

1. Outer diameter of knurled surface.

92CS-15207R3

Press-Fit
60- and 80-A Triacs

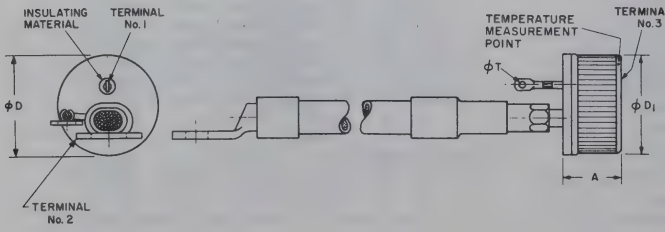

CATHODE SENSING TERMINAL (CONNECTOR FOR No. 6 STUD)
ϕT_2
TERMINAL No. 2 (CONNECTOR FOR 1/4 IN. STUD)
J_1
ϕT_1
J

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.466	–	11.84	
ϕD	0.751	0.760	19.08	19.30	
ϕD_1	–	0.7535	–	19.139	
J	6.8 NOM.		172.72 NOM.		1
J_1	6.3 NOM.		160.02 NOM.		1
ϕT	0.060	0.065	1.52	1.65	
ϕT_1	0.266	–	6.75	–	
ϕT_2	0.144	–	3.70	–	

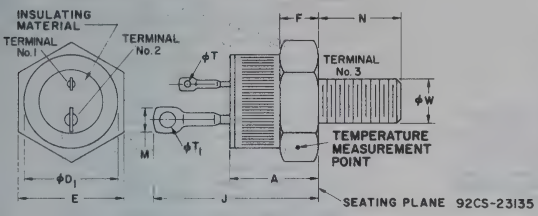
NOTE:

1: Leads J and J_1 available at various lengths. For information contact the RCA Sales Office in your locale.

92CM-22833


INSULATING MATERIAL
TERMINAL No. 1
ϕD
TERMINAL No. 2
TEMPERATURE MEASUREMENT POINT
TERMINAL No. 3
ϕT
ϕD_1
A

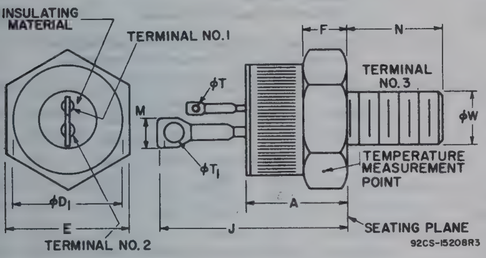
Stud 6-, 10, and 15-A Triacs; 20- and 35-A SCR's


INSULATING MATERIAL
TERMINAL No. I
TERMINAL No. 2
ϕT
ϕT₁
M
ϕD₁
E
F
N
TERMINAL No. 3
ϕW
TEMPERATURE MEASUREMENT POINT
A
J
SEATING PLANE
92CS-23135

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.330	0.505	8.40	12.80	
ϕD_1	–	0.544	–	13.81	
E	0.544	0.562	13.82	14.28	
F	0.113	0.200	2.87	5.08	
J	–	0.950	–	24.13	
M	–	0.155	–	3.94	
N	0.422	0.453	10.72	11.50	
ϕT	0.058	0.068	1.47	1.73	
ϕT_1	0.080	0.090	2.03	2.29	
ϕW	1/4-28 UNF-2A		1/4-28 UNF-2A		1

NOTE 1: ϕW is pitch diameter of coated threads.
REF. Screw-Thread Standard for Federal Services Handbook H28, Part I.
Recommended torque: 35 inch-pounds.

Stud 25-, 30-, and 40-A Triacs


INSULATING MATERIAL
TERMINAL NO. I
ϕT
M
ϕT₁
ϕD₁
E
TERMINAL NO. 2
F
N
TERMINAL NO. 3
ϕW
TEMPERATURE MEASUREMENT POINT
A
J
SEATING PLANE
92CS-15208R3

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.330	0.505	8.4	12.8	–
ϕD_1	–	0.544	–	13.81	–
E	0.544	0.562	13.82	14.28	–
F	0.113	0.200	2.87	5.08	–
J	0.950	1.100	24.13	27.94	–
M	0.215	0.225	5.46	5.71	–
N	0.422	0.453	10.72	11.50	–
ϕT	0.058	0.068	1.47	1.73	–
ϕT_1	0.138	0.148	3.51	3.75	–
ϕW	1/4-28 UNF-2A		1/4-28 UNF-2A		1

NOTE

1. ϕW is pitch diameter of coated threads.

REF: Screw-Thread Standards for Federal Services, Handbook H28, Part I. Recommended Torque: 25 inch-pounds.

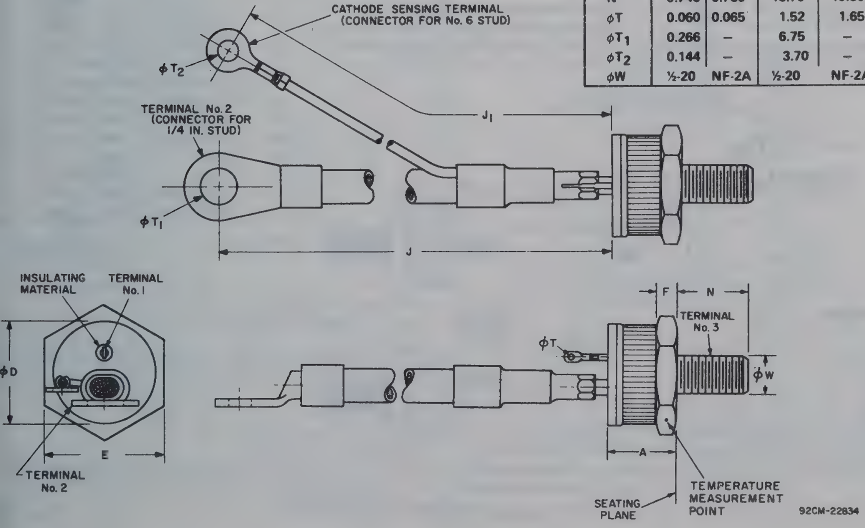
Stud 60- and 80-A Triacs

NOTES:

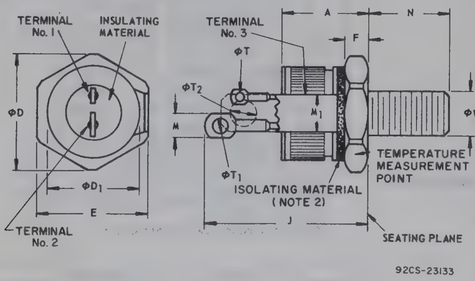
1: Leads J and J_1 available at various lengths. For information, contact the RCA Sales Office in your locale.

2: ϕW is pitch diameter of coated threads. REF: Screw Thread Standard for Federal Services, Handbook H 28 Part I. Recommended torque: 125 inch-pounds.

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.620	–	15.75	
ϕD	0.751	0.760	19.08	19.30	
E	0.866	0.872	21.99	22.14	
F	0.182	0.192	4.62	4.87	
J	6.8 NOM.		172.72 NOM.		1
J_1	6.3 NOM.		160.02 NOM.		1
N	0.740	0.760	18.79	19.30	
ϕT	0.060	0.065	1.52	1.65	
ϕT_1	0.266	–	6.75	–	
ϕT_2	0.144	–	3.70	–	
ϕW	½-20	NF-2A	½-20	NF-2A	2


CATHODE SENSING TERMINAL (CONNECTOR FOR No. 6 STUD)
ϕT₂
J₁
TERMINAL No. 2 (CONNECTOR FOR 1/4 IN. STUD)
ϕT₁
J
INSULATING MATERIAL
TERMINAL No. I
ϕD
E
TERMINAL No. 2
F
N
TERMINAL No. 3
ϕT
ϕW
A
SEATING PLANE
TEMPERATURE MEASUREMENT POINT
92CM-22834

Isolated-Stud 6-, 10-, and 15-A Triacs; 20- and 35-A SCR's


TERMINAL No. I
INSULATING MATERIAL
TERMINAL No. 3
A
N
F
ϕT
ϕT2
ϕD
M
M1
ϕW
ϕT1
TEMPERATURE MEASUREMENT POINT
ISOLATING MATERIAL (NOTE 2)
ϕD1
E
J
TERMINAL No. 2
SEATING PLANE
92CS-23133

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.673	–	17.09	
ϕD	0.604	0.614	15.34	15.59	
ϕD1	0.501	0.505	12.72	12.82	
E	0.551	0.557	13.99	14.14	
F	0.175	0.185	4.44	4.69	
J	–	1.055	–	26.79	
M	–	0.155	–	3.94	
M1	0.200	0.210	5.08	5.33	
N	0.422	0.452	10.72	11.48	
ϕT	0.058	0.068	1.47	1.73	
ϕT1	0.080	0.090	2.03	2.29	
ϕT2	0.138	0.148	3.50	3.75	
ϕW	1/4-28 UNF-2A		1/4-28 UNF-2A		1

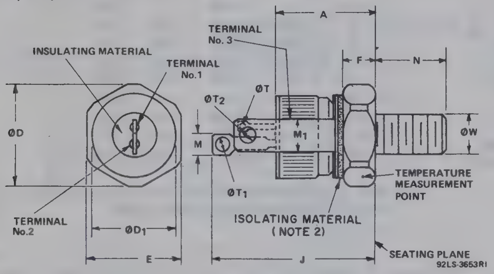
NOTE 1: ϕW is pitch diameter of coated threads. REF. Screw-Thread Standard for Federal Services Handbook H28, Part I.

Recommended torque: 35 inch-pounds.

NOTE 2:

Isolating material (ceramic) between hex (stud) and terminal No. 3 is beryllium oxide. Minimum isolation breakdown voltage is 2100 V rms for 1 minute duration.

Isolated-Stud 25-, 30-, and 40-A Triacs


A
TERMINAL No. 3
INSULATING MATERIAL
TERMINAL No.1
F
N
ØT
ØT2
ØD
M
M1
ØW
ØT1
TEMPERATURE MEASUREMENT POINT
ISOLATING MATERIAL (NOTE 2)
TERMINAL No.2
ØD1
E
J
SEATING PLANE
92LS-3653R1

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.673	–	17.09	–
ϕD	0.604	0.614	15.34	15.59	–
ϕD1	0.501	0.505	12.72	12.82	–
E	0.551	0.557	13.99	14.14	–
F	0.175	0.185	4.44	4.69	–
J	–	1.298	–	32.96	–
M	0.210	0.230	5.33	5.84	–
M1	0.200	0.210	5.08	5.33	–
N	0.422	0.452	10.72	11.48	–
ϕT	0.058	0.068	1.47	1.73	–
ϕT1	0.125	0.165	3.18	4.19	–
ϕT2	0.138	0.148	3.50	3.75	–
ϕW	¼-28 UNF-2 A		¼-28 UNF-2 A		1

NOTES:

1. ϕW is pitch diameter of coated threads. REF: Screw-Thread Standards for Federal Services, Handbook H28, Part I. Recommended Torque: 25 inch-pounds.
2. Isolating material (ceramic) between hex (stud) and terminal No. 3 is beryllium oxide. Minimum isolation breakdown voltage is 2100 V rms for 1 minute duration.

Isolated-Stud 60- and 80-A Triacs

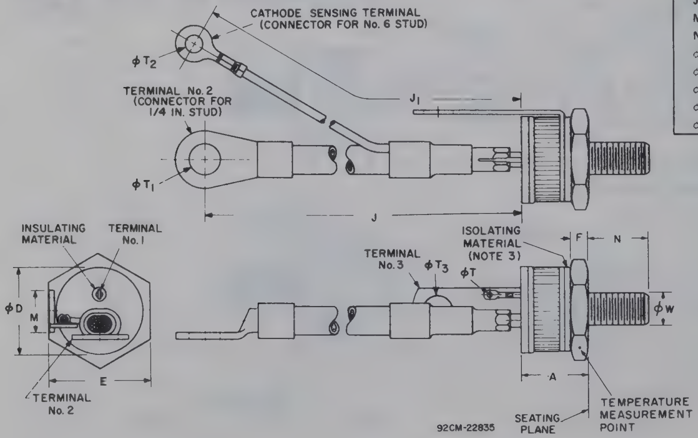
NOTES:

1: Leads J and J1 available at various lengths. For information, contact the RCA Sales Office in your locale.

2: ϕW is pitch diameter of coated threads. REF: Screw Thread Standards for Federal Services, Handbook H 28 Part I. Recommended torque: 125 inch-pounds.

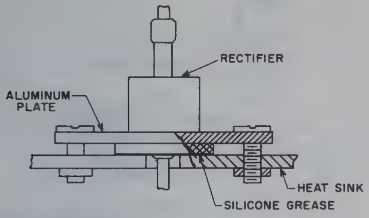
3: Isolating material (ceramic) between hex (stud) and terminal No. 3 is beryllium oxide. Minimum isolation breakdown voltage is 2100 V rms for 1 minute duration.

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.710	–	18.03	
ϕD1	0.751	0.760	19.08	19.30	
E	0.866	0.872	21.99	22.14	
F	0.182	0.192	4.62	4.87	
J	6.8 NOM.		172.72 NOM.		1
J1	6.3 NOM.		160.02 NOM.		1
M	0.375	0.385	9.52	9.78	
N	0.740	0.760	18.79	19.30	
ϕT	0.060	0.065	1.52	1.65	
ϕT1	0.266	–	6.75	–	
ϕT2	0.144	–	3.70	–	
ϕT3	0.195	0.205	4.95	5.20	
ϕW	½-20	NF-2A	½-20	NF-2A	2


CATHODE SENSING TERMINAL (CONNECTOR FOR No. 6 STUD)
ϕT2
TERMINAL No. 2 (CONNECTOR FOR 1/4 IN. STUD)
J1
ϕT1
J
INSULATING MATERIAL
TERMINAL No. I
ISOLATING MATERIAL (NOTE 3)
F
N
TERMINAL No. 3
ϕT3
ϕT
ϕD
M
ϕW
E
A
TERMINAL No. 2
SEATING PLANE
TEMPERATURE MEASUREMENT POINT
92CM-22835

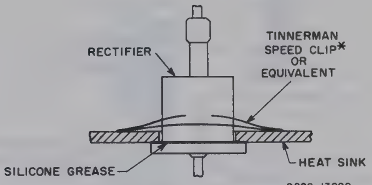
DO-1

For Rectifiers used in Power Supplies


RECTIFIER
ALUMINUM PLATE
HEAT SINK
SILICONE GREASE

DO-1

For Rectifiers used in SCR Horizontal-Deflection Circuits


RECTIFIER
TINNERMAN SPEED CLIP* OR EQUIVALENT
SILICONE GREASE
HEAT SINK

92CS-13090

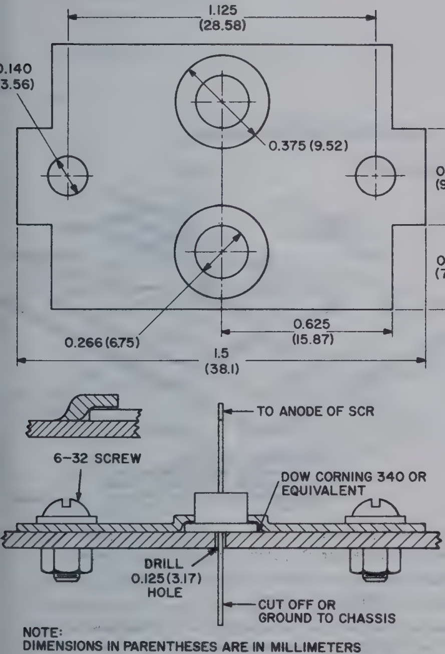
* Registered Trade Mark, Tinnerman Products, Inc., Cleveland 1, Ohio.

RECTIFIERS AND SCR's MOUNTED ON A COMMON HEAT SINK

The SCR's and rectifiers can be operated at full current only if they have an adequate heat sink. The procedure illustrated in Mtg. No. 1 should be used when mounting the SCR's. A single aluminum plate made as shown in Mtg. No. 1 will provide an adequate heat sink for trace and commutating rectifiers. Lip punching of the chassis at one end of the clamp plate make it possible to mount the rectifier using only one screw.

Optional clamp plate and mounting arrangement is shown in Mtg. No. 2. The "spacer" as shown should be of a thickness that will provide good thermal contact between heat sink and and rectifiers without excessive bending of the clamp plate.

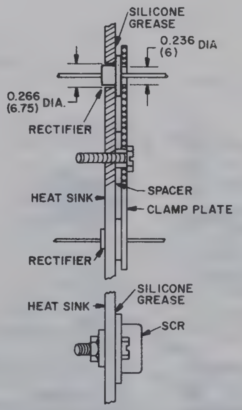
TO-66 package used for the SCR's fits socket PTS-4 (United International Dynamics Corp., 2029 Taft St., Hollywood, Fla.), or equivalent. Thermal grease (zinc oxide), Dow Corning 340 or equivalent, should be used on both sides of the insulating mica to assure efficient transfer of heat from the case of the device to the heat sink.


1.125 (28.58)
.140
3.56)
0.375 (9.52)
0.375 (9.53)
0.312 (7.92)
0.266 (6.75)
0.625 (15.87)
1.5 (38.1)
TO ANODE OF SCR
6-32 SCREW
DOW CORNING 340 OR EQUIVALENT
DRILL 0.125 (3.17) HOLE
CUT OFF OR GROUND TO CHASSIS

NOTE:
DIMENSIONS IN PARENTHESES ARE IN MILLIMETERS

Mtg. No. 1

92CS-17422


SILICONE GREASE
0.236 DIA (6)
0.266 (6.75) DIA.
RECTIFIER
SPACER
HEAT SINK
CLAMP PLATE
RECTIFIER
HEAT SINK
SILICONE GREASE
SCR

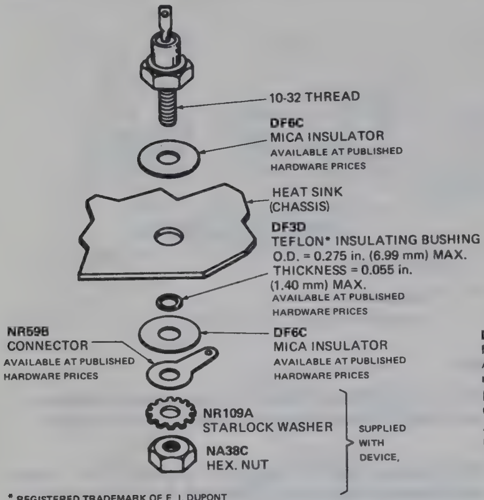
NOTE: DIMENSIONS IN PARENTHESES ARE MILLIMETERS

Mtg. No. 2

92CS-24050

In the United Kingdom Europe, Middle East, and Africa mounting hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

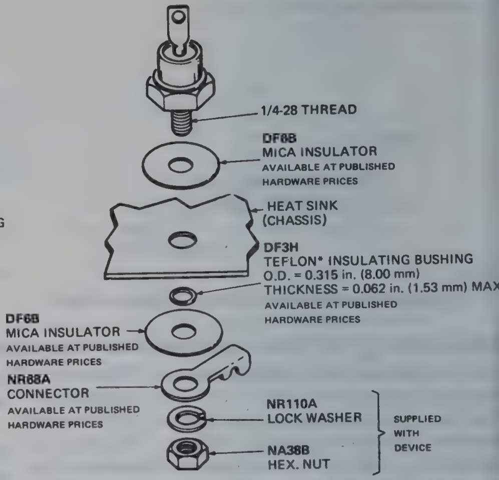
DO-4


10-32 THREAD
DF6C
MICA INSULATOR
AVAILABLE AT PUBLISHED HARDWARE PRICES
HEAT SINK (CHASSIS)
DF3D
TEFLON* INSULATING BUSHING
O.D. = 0.275 in. (6.99 mm) MAX.
THICKNESS = 0.055 in. (1.40 mm) MAX.
AVAILABLE AT PUBLISHED HARDWARE PRICES
NR59B
CONNECTOR
AVAILABLE AT PUBLISHED HARDWARE PRICES
DF6C
MICA INSULATOR
AVAILABLE AT PUBLISHED HARDWARE PRICES
NR109A
STARLOCK WASHER
NA38C
HEX. NUT
SUPPLIED WITH DEVICE,

* REGISTERED TRADEMARK OF E. I. DUPONT DE NEMOUR & CO.

92CS-22573

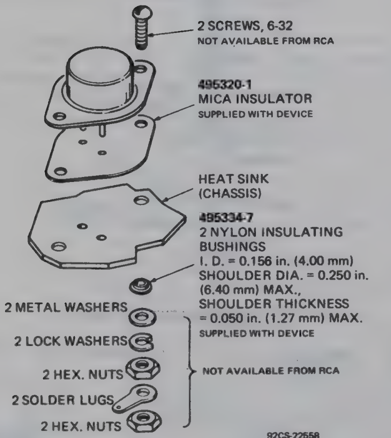
DO-5


1/4-28 THREAD
DF8B
MICA INSULATOR
AVAILABLE AT PUBLISHED HARDWARE PRICES
HEAT SINK (CHASSIS)
DF3H
TEFLON* INSULATING BUSHING
O.D. = 0.315 in. (8.00 mm)
THICKNESS = 0.062 in. (1.53 mm) MAX
AVAILABLE AT PUBLISHED HARDWARE PRICES
DF6B
MICA INSULATOR
AVAILABLE AT PUBLISHED HARDWARE PRICES
NR88A
CONNECTOR
AVAILABLE AT PUBLISHED HARDWARE PRICES
NR110A
LOCK WASHER
NA38B
HEX. NUT
SUPPLIED WITH DEVICE

92CS-22565

* REGISTERED TRADEMARK OF E. I. DUPONT DE NEMOUR & CO.

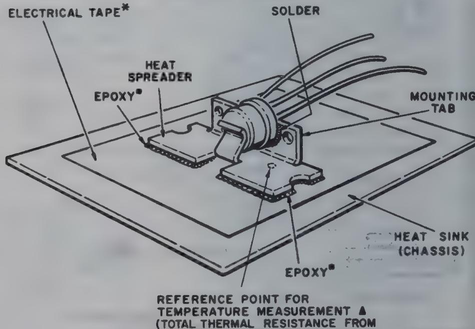
TO-3


2 SCREWS, 6-32
NOT AVAILABLE FROM RCA
495320-1
MICA INSULATOR
SUPPLIED WITH DEVICE
HEAT SINK (CHASSIS)
495334-7
2 NYLON INSULATING BUSHINGS
I. D. = 0.156 in. (4.00 mm)
SHOULDER DIA. = 0.250 in. (6.40 mm) MAX.,
SHOULDER THICKNESS = 0.050 in. (1.27 mm) MAX.
SUPPLIED WITH DEVICE
2 METAL WASHERS
2 LOCK WASHERS
2 HEX. NUTS
2 SOLDER LUGS
2 HEX. NUTS
NOT AVAILABLE FROM RCA

92CS-22558

Note: Maximum torque applied to mounting flange is 12 in.-lb.

"LOW - Profile TO-5" with Heat Spreader


ELECTRICAL TAPE*
SOLDER
HEAT SPREADER
EPOXY■
MOUNTING TAB
HEAT SINK (CHASSIS)
EPOXY■
REFERENCE POINT FOR TEMPERATURE MEASUREMENT ▲
(TOTAL THERMAL RESISTANCE FROM JUNCTION TO HEAT SINK = 10 °C/W)

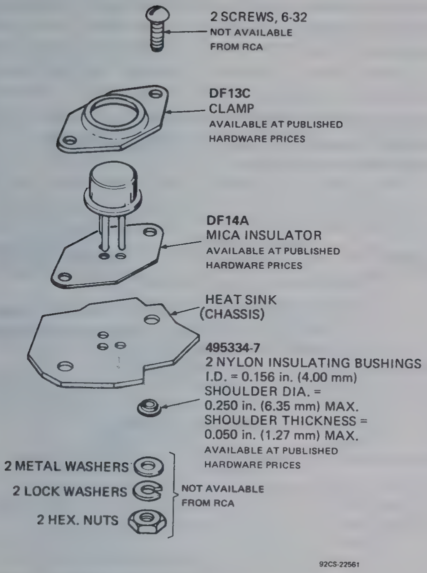
92SS-3898R2

* Scotch brand electrical tape No.27 (thermo setting one side), Minnesota Mining & Mfg. Co., St Paul, Minnesota, or equivalent.

■ An epoxy such as Hysol Epoxy Patch Kit 6C, Hysol Corporation, Olean, N. Y. 14761, or equivalent.

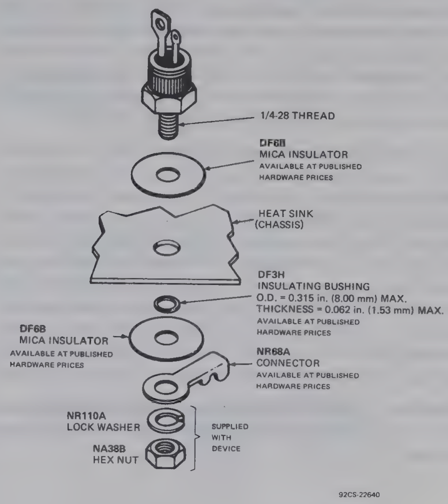
▲ For heat-sink temperature measurement, the thermocouple (wire no larger than AWG No. 26) should be inserted in a small, shallow hole drilled in (but not through) the heat sink at the indicated temperature reference point.

TO-8

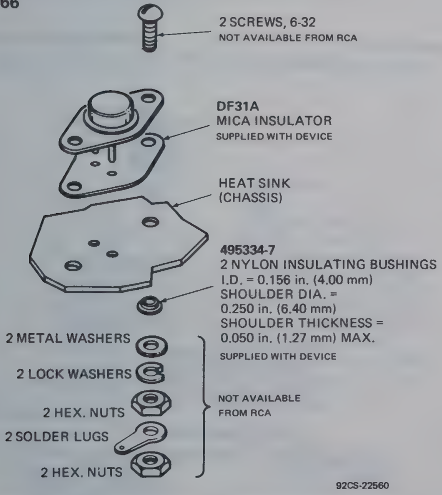

2 SCREWS, 6-32
NOT AVAILABLE
FROM RCA
DF13C
CLAMP
AVAILABLE AT PUBLISHED
HARDWARE PRICES
DF14A
MICA INSULATOR
AVAILABLE AT PUBLISHED
HARDWARE PRICES
HEAT SINK
(CHASSIS)
495334-7
2 NYLON INSULATING BUSHINGS
I.D. = 0.156 in. (4.00 mm)
SHOULDER DIA. =
0.250 in. (6.35 mm) MAX.
SHOULDER THICKNESS =
0.050 in. (1.27 mm) MAX.
AVAILABLE AT PUBLISHED
HARDWARE PRICES
2 METAL WASHERS
2 LOCK WASHERS
2 HEX. NUTS
NOT AVAILABLE
FROM RCA
92CS-22561

Note: Maximum torque applied to mounting flange is 12 in.-lb.

TO-48

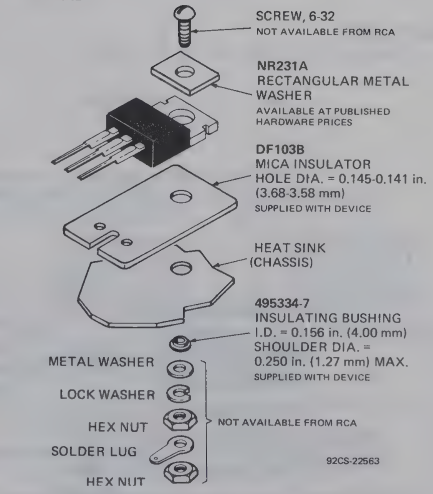

1/4-28 THREAD
DF6B
MICA INSULATOR
AVAILABLE AT PUBLISHED
HARDWARE PRICES
HEAT SINK
(CHASSIS)
DF3H
INSULATING BUSHING
O.D. = 0.315 in. (8.00 mm) MAX.
THICKNESS = 0.062 in. (1.53 mm) MAX.
AVAILABLE AT PUBLISHED
HARDWARE PRICES
DF6B
MICA INSULATOR
AVAILABLE AT PUBLISHED
HARDWARE PRICES
NR68A
CONNECTOR
AVAILABLE AT PUBLISHED
HARDWARE PRICES
NR110A
LOCK WASHER
NA38B
HEX NUT
SUPPLIED
WITH
DEVICE
92CS-22640

TO-66


2 SCREWS, 6-32
NOT AVAILABLE FROM RCA
DF31A
MICA INSULATOR
SUPPLIED WITH DEVICE
HEAT SINK
(CHASSIS)
495334-7
2 NYLON INSULATING BUSHINGS
I.D. = 0.156 in. (4.00 mm)
SHOULDER DIA. =
0.250 in. (6.40 mm)
SHOULDER THICKNESS =
0.050 in. (1.27 mm) MAX.
SUPPLIED WITH DEVICE
2 METAL WASHERS
2 LOCK WASHERS
2 HEX. NUTS
2 SOLDER LUGS
2 HEX. NUTS
NOT AVAILABLE
FROM RCA
92CS-22560

Note: Maximum torque applied to mounting flange is 12 in-lb.

TO-220AB


SCREW, 6-32
NOT AVAILABLE FROM RCA
NR231A
RECTANGULAR METAL
WASHER
AVAILABLE AT PUBLISHED
HARDWARE PRICES
DF103B
MICA INSULATOR
HOLE DIA. = 0.145-0.141 in.
(3.68-3.58 mm)
SUPPLIED WITH DEVICE
HEAT SINK
(CHASSIS)
495334-7
INSULATING BUSHING
I.D. = 0.156 in. (4.00 mm)
SHOULDER DIA. =
0.250 in. (1.27 mm) MAX.
SUPPLIED WITH DEVICE
METAL WASHER
LOCK WASHER
HEX NUT
SOLDER LUG
HEX NUT
NOT AVAILABLE FROM RCA
92CS-22563

Note: Maximum torque applied to mounting flange is 8 in-lb.

Press-Fit
Triacs and SCR's except 60- and 80-A Triacs

MOUNTING CONSIDERATIONS

Mounting of press-fit package types depends upon an interference fit between the thyristor case and the heat sink. As the thyristor is forced into the heat-sink hole, metal from the heat sink flows into the knurl voids of the thyristor case. The resulting close contact between the heat sink and the thyristor case assures low thermal and electrical resistances.

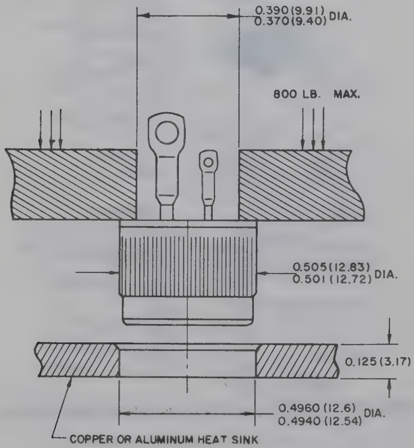
A recommended mounting method, Press-Fit (PF-1) or Press-Fit (PF-2), shows press-fit knurl and heat-sink hole dimensions. If these dimensions are maintained, a "worst-case" condition of 0.0085 in. (0.2159 mm) interference fit will allow press-fit insertion below the maximum allowable insertion force of 800 pounds. A slight chamfer in the heat-sink hole will help center and guide the press-fit package properly into the heat sink. The insertion tool should be a hollow shaft having an inner diameter of 0.380 ± 0.010 in. (9.65 ± 0.254 mm) for PF-1 package, and 0.410 ± 0.010 in. (10.41 ± 0.254 mm) for PF-2 package and an outer diameter of 0.500 in (12.70 mm). These dimensions provide sufficient clearance for the leads and assure that no direct force will be applied to the glass seal of the thyristor.

The press-fit package is not restricted to a single mounting arrangement; direct soldering and the use of epoxy adhesives have been successfully employed. The press-fit case is tin-plated to facilitate direct soldering to the heat sink. A 60-40 solder should be used and heat should be applied only long enough to allow the solder to flow freely.

Case-to-Heat Sink Thermal Resistance for Different Mounting Arrangements—Triacs and SCR's except 60- and 80-A Triacs

Package	Type of Mounting Employed	Thermal Resistance-°C/W
Press-Fit	Press-fitted into heat sink. Minimum required thickness of heat sink = 1/8 in. (3.17 mm).	0.5
	Soldered directly to heat sink. (60-40 solder which has a melting point of 188°C should be used. Heating time should be sufficient to cause solder to flow freely).	0.1 to 0.35

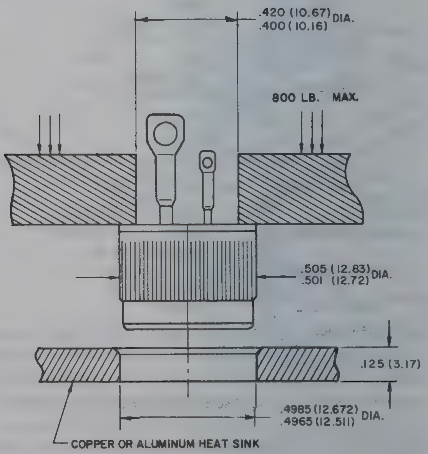
Press-Fit (PF-1)
6-, 10-, and 15-A Triacs, 20- and 35-A SCR's



NOTE: Dimensions in parentheses are in millimeters

92SS-3912R1

Press-Fit (PF-2)
25-, 30-, and 40-A Triacs



NOTE: Dimensions in parentheses are in millimeters

92LS-2264R4

Press-Fit with Flexible Leads
60- and 80-A Triacs

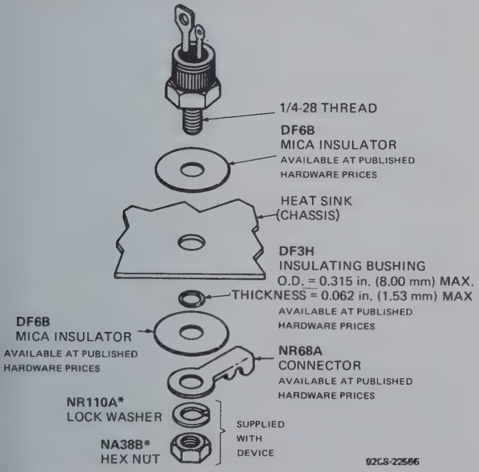
MOUNTING CONSIDERATIONS

A mounting method, Press-Fit (PF-3), shows press-fit knurl and heat-sink hole dimensions. If these dimensions are maintained, a "worst-case" condition of 0.0085 in. (0.2159 mm) interference fit will allow press-fit insertion below the maximum allowable insertion force of 800 pounds. A slight chamfer in the heat-sink hole will help center and guide the press-fit package properly into the heat sink. The insertion tool should be a hollow shaft having an inner diameter of 0.6125 ± 0.0375 in. (15.56 ± 0.952 mm) and an outer diameter of 0.750 in. (19.05 mm). These dimensions provide sufficient clearance for the leads and assure that no direct force will be applied to the glass seals of the thyristor. *Press-fit type mounting is not recommended for triacs operating at maximum rated rms current.*

Case-to-Heat Sink Thermal Resistance for Different Mounting Arrangements — 60- and 80-A Triacs

Package	Type of Mounting Employed	Thermal Resistance-°C/W
Press-Fit	Press-fitted into heat sink. Minimum required thickness of heat sink = 0.25 in. (6.35 mm)	0.4
	Soldered directly to heat sink. (60-40 solder which has a melting point of 188°C should be used. Heating time should be sufficient to cause solder to flow freely). THIS METHOD RECOMMENDED FOR MAXIMUM HEAT TRANSFER	0.012 to 0.036 For 1 to 3 mil thick solder layer

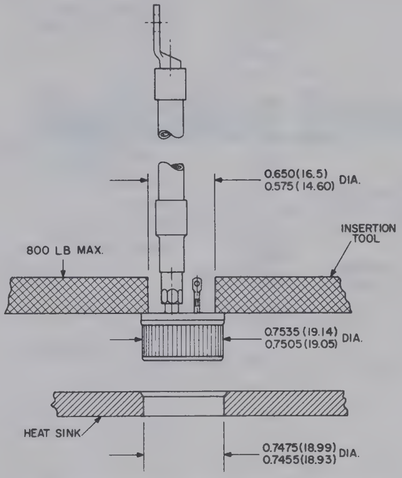
Stud and Isolated-Stud
Triacs and SCR's except 60- and 80-A Triacs


1/4-28 THREAD
DF6B
MICA INSULATOR
AVAILABLE AT PUBLISHED HARDWARE PRICES
HEAT SINK (CHASSIS)
DF3H
INSULATING BUSHING
O.D. = 0.315 in. (8.00 mm) MAX.
THICKNESS = 0.062 in. (1.53 mm) MAX
AVAILABLE AT PUBLISHED HARDWARE PRICES
DF6B
MICA INSULATOR
AVAILABLE AT PUBLISHED HARDWARE PRICES
NR68A
CONNECTOR
AVAILABLE AT PUBLISHED HARDWARE PRICES
NR110A*
LOCK WASHER
NA38B*
HEX NUT
SUPPLIED WITH DEVICE
92CS-22566

* Only hardware required for isolated-stud package.

When using the 60- or 80-A press-fit triac at the maximum rated current, a minimum thermal path can be achieved between the package and heat sink. Direct soldering of the press-fit package to the heat sink can accomplish a minimum thermal path. The press-fit package is tin plated to facilitate direct soldering. A 60-40 solder should be used and heat should be applied only long enough to allow the solder to flow freely.

Press-Fit (PF-3)
60- and 80-A Triacs

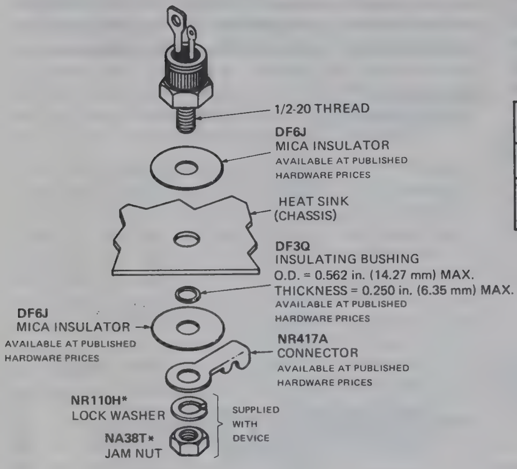

0.650(16.5)
0.575(14.60) DIA.
INSERTION TOOL
800 LB MAX.
0.7535(19.14)
0.7505(19.05) DIA.
HEAT SINK
0.7475(18.99)
0.7455(18.93) DIA.

NOTE: Dimensions in parentheses are in millimeters 92CS-22836

Case-to-Heat Sink Thermal Resistance for Different Mounting Arrangements—Triacs and SCR's except 60- and 80-A Triacs

Package	Type of Mounting Employed	Resistance-°C/W
Stud & Isolated-Stud	Directly mounted on heat sink with or without the use of heat-sink compound.	0.6
Stud	Mounted on heat sink with a 0.004 to 0.006 in. (0.102 to 0.152 mm) thick mica insulating washer used between unit and heat sink.	
	Without heat sink compound	2.5
	With heat sink compound	1.5

Stud and Isolated-Stud
60- and 80-A Triacs


1/2-20 THREAD
DF6J
MICA INSULATOR
AVAILABLE AT PUBLISHED HARDWARE PRICES
HEAT SINK (CHASSIS)
DF3Q
INSULATING BUSHING
O.D. = 0.562 in. (14.27 mm) MAX.
THICKNESS = 0.250 in. (6.35 mm) MAX.
AVAILABLE AT PUBLISHED HARDWARE PRICES
DF6J
MICA INSULATOR
AVAILABLE AT PUBLISHED HARDWARE PRICES
NR417A
CONNECTOR
AVAILABLE AT PUBLISHED HARDWARE PRICES
NR110H*
LOCK WASHER
NA38T*
JAM NUT
SUPPLIED WITH DEVICE
92CS-22843

* Only hardware required for isolated-stud package.

Case-to-Heat Sink Thermal Resistance for Different Mounting Arrangements — 60- and 80-A Triacs

Package	Type of Mounting Employed	Resistance-°C/W
Stud	Directly mounted on heat sink with or without the use of heat sink compound	0.05 to 0.15
Isolated Stud		0.1 to 0.2

For additional information on mounting RCA thyristors, refer to Application Note AN-3822, "Thermal Considerations in Mounting of RCA Thyristors"

Application Notes

Operating Considerations for RCA Solid State Devices

Solid state devices are being designed into an increasing variety of electronic equipment because of their high standards of reliability and performance. However, it is essential that equipment designers be mindful of good engineering practices in the use of these devices to achieve the desired performance.

This Note summarizes important operating recommendations and precautions which should be followed in the interest of maintaining the high standards of performance of solid state devices.

The ratings included in RCA Solid State Devices data bulletins are based on the Absolute Maximum Rating System, which is defined by the following Industry Standard (JEDEC) statement:

Absolute-Maximum Ratings are limiting values of operating and environmental conditions applicable to any electron device of a specified type as defined by its published data, and should not be exceeded under the worst probable conditions.

The device manufacturer chooses these values to provide acceptable serviceability of the device, taking no responsibility for equipment variations, environmental variations, and the effects of changes in operating conditions due to variations in device characteristics.

The equipment manufacturer should design so that initially and throughout life no absolute-maximum value for the intended service is exceeded with any device under the worst probable operating conditions with respect to supply-voltage variation, equipment component variation, equipment control adjustment, load variation, signal variation, environmental conditions, and variations in device characteristics.

It is recommended that equipment manufacturers consult RCA whenever device applications involve unusual electrical, mechanical or environmental operating conditions.

GENERAL CONSIDERATIONS

The design flexibility provided by these devices makes possible their use in a broad range of applications and under many different operating conditions. When incorporating these devices in equipment, therefore, designers should anticipate the rare possibility of device failure and make certain that no safety hazard would result from such an occurrence.

The small size of most solid state products provides obvious advantages to the designers of electronic equipment. However, it should be recognized that these compact devices usually provide only relatively small insulation area between adjacent leads and the metal envelope. When these devices are used in moist or contaminated atmospheres, therefore, supplemental protection must be provided to prevent the development of electrical conductive paths across the relatively small insulating surfaces. For specific information on voltage creepage, the user should consult references such as the JEDEC Standard No. 7 "Suggested Standard on Thyristors," and JEDEC Standard RS282 "Standards for Silicon Rectifier Diodes and Stacks".

The metal shells of some solid state devices operate at the collector voltage and for some rectifiers and thyristors at the anode voltage. Therefore, consideration should be given to the possibility of shock hazard if the shells are to operate at voltages appreciably above or below ground potential. In general, in any application in which devices are operated at voltages which may be dangerous to personnel, suitable precautionary measures should be taken to prevent direct contact with these devices.

Devices should not be connected into or disconnected from circuits with the power on because high transient voltages may cause permanent damage to the devices.

TESTING PRECAUTIONS

In common with many electronic components, solid-state devices should be operated and tested in circuits which have reasonable values of current limiting resistance, or other forms of effective current overload protection. Failure to observe these precautions can cause excessive internal heating of the device resulting in destruction and/or possible shattering of the enclosure.

TRANSISTORS AND THYRISTORS WITH FLEXIBLE LEADS

Flexible leads are usually soldered to the circuit elements. It is desirable in all soldering operatings to provide some slack or an expansion elbow in each lead to prevent excessive tension on the leads. It is important during the soldering operation to avoid excessive heat in order to prevent possible damage to the devices. Some of the heat can be absorbed if the flexible lead of the device is grasped between the case and the soldering point with a pair of pliers.

TRANSISTORS AND THYRISTORS WITH MOUNTING FLANGES

The mounting flanges of JEDEC-type packages such as the TO-3 or TO-66 often serve as the collector or anode terminal. In such cases, it is essential that the mounting flange be securely fastened to the heat sink, which may be the equipment chassis. Under no circumstances, however, should the mounting flange of a transistor be soldered directly to the heat sink or chassis because the heat of the soldering operation could permanently damage the device. Soldering is the preferred method for mounting thyristors; see "Rectifiers and Thyristors," below. Devices which cannot be soldered can be installed in commercially available sockets. Electrical connections may also be made by soldering directly to the terminal pins. Such connections may be soldered to the pins close to the pin seals provided care is taken to conduct excessive heat away from the seals; otherwise the heat of the soldering operation could crack the pin seals and damage the device.

During operation, the mounting-flange temperature is higher than the ambient temperature by an amount which depends on the heat sink used. The heat sink must have sufficient thermal capacity to assure that the heat dissipated in the heat sink itself does not raise the device mounting-flange temperature above the rated value. The heat sink or chassis may be connected to either the positive or negative supply.

In many applications the chassis is connected to the voltage-supply terminal. If the recommended mounting hardware shown in the data bulletin for the specific solid-state device is not available, it is necessary to use either an anodized aluminum insulator having high thermal conductivity or a mica insulator between the mounting-flange and the chassis. If an insulating aluminum washer is required, it should be drilled or punched to provide the two mounting holes for the terminal pins. The burrs should then be removed from the washer and the washer anodized. To insure that the anodized insulating layer is not destroyed during mounting, it is necessary to remove the burrs from the holes in the chassis.

It is also important that an insulating bushing, such as glass-filled nylon, be used between each mounting bolt and the chassis to prevent a short circuit. However, the insulating bushing should not exhibit shrinkage or softening under the operating temperatures encountered. Otherwise the thermal resistance at the interface between device and heat sink may increase as a result of decreasing pressure.

PLASTIC POWER TRANSISTORS AND THYRISTORS

RCA power transistors and thyristors (SCR's and triacs) in molded-silicone-plastic packages are available in a wide range of power-dissipation ratings and a variety of package configurations. The following paragraphs provide guidelines for handling and mounting of these plastic-package devices, recommend forming of leads to meet specific mounting requirements, and describe various mounting arrangements, thermal considerations, and cleaning methods. This information is intended to augment the data on electrical characteristics, safe operating area, and performance capabilities in the technical bulletin for each type of plastic-package transistor or thyristor.

Lead-Forming Techniques

The leads of the RCA VERSAWATT in-line plastic packages can be formed to a custom shape, provided they are not indiscriminately twisted or bent. Although these leads can be formed, they are not flexible in the general sense, nor are they sufficiently rigid for unrestrained wire wrapping

Before an attempt is made to form the leads of an in-line package to meet the requirements of a specific application, the desired lead configuration should be determined, and a lead-bending fixture should be designed and constructed. The use of a properly designed fixture for this operation eliminates the need for repeated lead bending. When the use of a special bending fixture is not practical, a pair of long-nosed pliers may be used. The pliers should hold the lead firmly between the bending point and the case, but should not touch the case.

When the leads of an in-line plastic package are to be formed, whether by use of long-nosed pliers or a special bending fixture, the following precautions must be observed to avoid internal damage to the device:

1. Restrain the lead between the bending point and the plastic case to prevent relative movement between the lead and the case.
2. When the bend is made in the plane of the lead (spreading), bend only the narrow part of the lead.
3. When the bend is made in the plane perpendicular to that of the leads, make the bend at least 1/8 inch from the plastic case.
4. Do not use a lead-bend radius of less than 1/16 inch.
5. Avoid repeated bending of leads.

The leads of the TO-220AB VERSAWATT in-line package are not designed to withstand excessive axial pull. Force in this direction greater than 4 pounds may result in permanent damage to the device. If the mounting arrangement tends to impose axial stress on the leads, some method of strain relief should be devised.

Wire wrapping of the leads is permissible, provided that the lead is restrained between the plastic case and the point of the wrapping. Soldering to the leads is also allowed. The maximum soldering temperature, however, must not exceed 275°C and must be applied for not more than 5 seconds at a distance not less than 1/8 inch from the plastic case. When wires are used for connections, care should be exercised to assure that movement of the wire does not cause movement of the lead at the lead-to-plastic junctions.

The leads of RCA molded-plastic high-power packages are not designed to be reshaped. However, simple bending of the leads is permitted to change them from a standard vertical to a standard horizontal configuration, or conversely. Bending of the leads in this manner is restricted to three 90-degree bends; repeated bendings should be avoided.

Mounting

Recommended mounting arrangements and suggested hardware for the VERSAWATT package are given in the data bulletins for specific devices and in RCA Application Note AN-4142. When the package is fastened to a heat sink, a rectangular washer (RCA Part No. NR231A) is recommended to minimize distortion of the mounting flange. Excessive distortion of the flange could cause damage to the package. The washer is particularly important when the size of the mounting hole exceeds 0.140 inch (6-32 clearance). Larger holes are needed to accommodate insulating bushings; however, the holes should not be larger than necessary to provide hardware clearance and, in any case, should not exceed a diameter of 0.250 inch.

Flange distortion is also possible if excessive torque is used during mounting. A maximum torque of 8 inch-pounds is specified. Care should be exercised to assure that the tool used to drive the mounting screw never comes in contact with the plastic body during the driving operation. Such contact can result in damage to the plastic body and internal device connections. An excellent method of avoiding this problem is to use a spacer or combination spacer-isolating bushing which raises the screw head or nut above the top surface of the plastic body. The material used for such a spacer or spacer-isolating bushing should, of course, be carefully selected to avoid "cold flow" and consequent reduction in mounting force. Suggested materials for these bushings are diallphtalate, fiberglass-filled nylon, or fiberglass-filled polycarbonate. Unfilled nylon should be avoided.

Modification of the flange can also result in flange distortion and should not be attempted. The package should not be soldered to the heat sink by use of lead-tin solder because the heat required with this type of solder will cause the junction temperature of the device to become excessively high.

The TO-220AA plastic package can be mounted in commercially available TO-66 sockets, such as UID Electronics Corp. Socket No. PTS-4 or equivalent. For testing purposes, the TO-220AB in-line package can be mounted in a Jetron Socket No. DC74-104 or equivalent. Regardless of the mounting method, the following precautions should be taken:

1. Use appropriate hardware.
2. Always fasten the package to the heat sink before the leads are soldered to fixed terminals.
3. Never allow the mounting tool to come in contact with the plastic case.
4. Never exceed a torque of 8 inch-pounds.
5. Avoid oversize mounting holes.
6. Provide strain relief if there is any probability that axial stress will be applied to the leads.
7. Use insulating bushings to prevent hot-creep problems. Such bushings should be made of diallphthalate, fiberglass-filled nylon, or fiberglass-filled polycarbonate.

The maximum allowable power dissipation in a solid state device is limited by the junction temperature. An important factor in assuring that the junction temperature remains below the specified maximum value is the ability of the associated thermal circuit to conduct heat away from the device.

When a solid state device is operated in free air, without a heat sink, the steady-state thermal circuit is defined by the junction-to-free-air thermal resistance given in the published data for the device. Thermal considerations require that a free flow of air around the device is always present and that the power dissipation be maintained below the level which would cause the junction temperature to rise above the maximum rating. However, when the device is mounted on a heat sink, care must be taken to assure that all portions of the thermal circuit are considered.

To assure efficient heat transfer from case to heat sink when mounting RCA molded-plastic solid state power devices, the following special precautions should be observed:

1. Mounting torque should be between 4 and 8 inch-pounds.
2. The mounting holes should be kept as small as possible.
3. Holes should be drilled or punched clean with no burrs or ridges, and chamfered to a maximum radius of 0.010 inch.
4. The mounting surface should be flat within 0.002 inch/inch.
5. Thermal grease (Dow Corning 340 or equivalent) should always be used on both sides of the insulating washer if one is employed.
6. Thin insulating washers should be used. (Thickness of factory-supplied mica washers range from 2 to 4 mils).
7. A lock washer or torque washer, made of material having sufficient creep strength, should be used to prevent degradation of heat sink efficiency during life.

A wide variety of solvents is available for degreasing and flux removal. The usual practice is to submerge components in a solvent bath for a specified time. However, from a reliability stand point it is extremely important that the solvent, together with other chemicals in the solder-cleaning system (such as flux and solder covers), do not adversely affect the life of the component. This consideration applies to all non-hermetic and molded-plastic components.

It is, of course, impractical to evaluate the effect on long-term device life of all cleaning solvents, which are marketed with numerous additives under a variety of brand names. These solvents can, however, be classified with respect to their component parts as either acceptable or unacceptable. Chlorinated solvents tend to dissolve the outer package and, therefore, make operation in a humid atmosphere unreliable. Gasoline and other hydrocarbons cause the inner encapsulant to swell and damage the transistor. Alcohol is an acceptable solvent. Examples of specific, acceptable alchols are isopropanol, methanol, and special denatured alcohols, such as SDA1, SDA30, SDA34, and SDA44.

Care must also be used in the selection of fluxes for lead soldering. Rosin or activated rosin fluxes are recommended, while organic or acid fluxes are not. Examples of acceptable fluxes are:

1. Alpha Reliaros No. 320-33
2. Alpha Reliaros No. 346
3. Alpha Reliaros No. 711
4. Alpha Reliafoam No. 807
5. Alpha Reliafoam No. 809
6. Alpha Reliafoam No. 811-13
7. Alpha Reliafoam No. 815-35
8. Kester No. 44

If the completed assembly is to be encapsulated, the effect on the molded-plastic transistor must be studied from both a chemical and a physical standpoint.

RECTIFIERS AND THYRISTORS

A surge-limiting impedance should always be used in series with silicon rectifiers and thyristors. The impedance value must be sufficient to limit the surge current to the value specified under the maximum ratings. This impedance may be provided by the power transformer winding, or by an external resistor or choke.

A very efficient method for mounting thyristors utilizing the "modified TO-5" package is to provide intimate contact between the heat sink and at least one half of the base of the device opposite the leads. This package can be mounted to the heat sink mechanically with glue or an expoxy adhesive, or by soldering, the most efficient method.

The use of a "self-jigging" arrangement and a solder preform is recommended. If each unit is soldered individually, the heat source should be held on the heat sink and the solder on the unit. Heat should be applied only long enough to permit solder to flow freely. For more detailed thyristor mounting considerations, refer to Application Note AN3822, "Thermal Considerations in Mounting of RCA Thyristors".

MOS FIELD-EFFECT TRANSISTORS

Insulated-Gate Metal Oxide-Semiconductor Field-Effect Transistors (MOS FETs), like bipolar high-frequency transistors, are susceptible to gate insulation damage by the electrostatic discharge of energy through the devices. Electrostatic discharges can occur in an MOS FET if a type with an unprotected gate is picked up and the static charge, built in the handler's body capacitance, is discharged through the device. With proper handling and applications procedures, however, MOS transistors are currently being extensively used in production by numerous equipment manufacturers in military, industrial, and consumer applications, with virtually no problems of damage due to electrostatic discharge.

In some MOS FETs, diodes are electrically connected between each insulated gate and the transistor's source. These diodes offer protection against static discharge and in-circuit transients without the need for external shorting mechanisms. MOS FETs which do not include gate-protection diodes can be handled safely if the following basic precautions are taken:

1. Prior to assembly into a circuit, all leads should be kept shorted together either by the use of metal shorting springs attached to the device by the vendor, or by the insertion into conductive material such as "ECCOSORB* LD26" or equivalent.
   (NOTE: Polystyrene *insulating* "SNOW" is not sufficiently conductive and should not be used.)
2. When devices are removed by hand from their carriers, the hand being used should be grounded by any suitable means, for example, with a metallic wristband.
3. Tips of soldering irons should be grounded.
4. Devices should never be inserted into or removed from circuits with power on.

RF POWER TRANSISTORS

Mounting and Handling

Stripline rf devices should be mounted so that the leads are not bent or pulled away from the stud (heat sink) side of the device. When leads are formed, they should be supported to avoid transmitting the bending or cutting stress to the ceramic portion of the device. Excessive stresses may destroy the hermeticity of the package without displaying visible damage.

Devices employing silver leads are susceptible to tarnishing; these parts should not be removed from the original tarnish-preventive containers and wrappings until ready for use. Lead solderability is retarded by the presence of silver tarnish; the tarnish can be removed with a silver cleaning solution, such as thiourea.

The ceramic bodies of many rf devices contain beryllium oxide as a major ingredient. These portions of the transistors should not be crushed, ground, or abraded in any way because the dust created could be hazardous if inhaled.

Operating

Forward-Biased Operation. For Class A or AB operation, the allowable quiescent bias point is determined by reference to the infrared safe-area curve in the appropriate data bulletin. This curve depicts the safe current/voltage combinations for extended continuous operation.

Load VSWR. Excessive collector load or tuning mismatch can cause device destruction by over-dissipation or secondary breakdown. Mismatch capability is generally included on the data bulletins for the more recent rf transistors.

See RCA RF Power Transitor Manual, Technical Series RMF-430, pp 39-41, for additional information concerning the handling and mounting of rf power transistors.

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*Trade Mark: Emerson and Cumming, Inc.

INTEGRATED CIRCUITS

Handing

All COS/MOS gate inputs have a resistor/diode gate protection network. All transmission gate inputs and all outputs have diode protection provided by inherent p-n junction diodes. These diode networks at input and output interfaces protect COS/MOS devices from gate-oxide failure in handling environments where static discharge is not excessive. In low-temperature, low-humidity environments, improper handling may result in device damage. See ICAN-6000, "Handling and Operating Considerations for MOS Integrated Circuits", for proper handling procedures.

Mounting

Integrated circuits are normally supplied with lead-tin plated leads to facilitate soldering into circuit boards. In those relatively few applications requiring welding of the device leads, rather than soldering, the devices may be obtained with gold or nickel plated Kovar leads.* It should be recognized that this type of plating will not provide complete protection against lead corrosion in the presence of high humidity and mechanical stress. The aluminum-foil-lined cardboard "sandwich pack" employed for static protection of the flat-pack also provides some additional protection against lead corrosion, and it is recommended that the devices be stored in this package until used.

When integrated circuits are welded onto printed circuit boards or equipment, the presence of moisture between the closely spaced terminals can result in conductive paths that may impair device performance in high-impedance applications. It is therefore recommended that conformal coatings or potting be provided as an added measure of protection against moisture penetration.

In any method of mounting integrated circuits which involves bending or forming of the device leads, it is extremely important that the lead be supported and clamped between the bend and the package seal, and that bending be done with care to avoid damage to lead plating. In no case should the radius of the bend be less than the diameter of the lead, or in the case of rectangular leads, such as those used in RCA 14-lead and 16-lead flat-packages, less than the lead thickness. It is also extremely important that the ends of the bent leads be straight to assure proper insertion through the holes in the printed-circuit board.

Operating

Unused Inputs

All unused input leads must be connected to either V_{SS} or V_{DD}, whichever is appropriate for the logic circuit involved. A floating input on a high-current type, such as the CD4049 or CD4050, not only can result in faulty logic operation, but can cause the maximum power dissipation of 200 milliwatts to be exceeded and may result in damage to the device. Inputs to these types, which are mounted on printed-circuit boards that may temporarily become unterminated, should have a pull-up resistor to V_{SS} or V_{DD}. A useful range of values for such resistors is from 10 kilohms to 1 megohm.

Input Signals

Signals shall not be applied to the inputs while the device power supply is off unless the input current is limited to a steady state value of less than 10 milliamperes. Input currents of less than 10 milliamperes prevent device damage; however, proper operation may be impaired as a result of current flow through structural diode junctions.

Output Short Circuits

Shorting of outputs to V_{SS} or V_{DD} can damage many of the higher-output-current COS/MOS types, such as the CD4007, CD4041, CD4049, and CD4050. In general, these types can all be safely shorted for supplies up to 5 volts, but will be damaged (depending on type) at higher power-supply voltages. For cases in which a short-circuit load, such as the base of a p-n-p or an n-p-n bipolar transistor, is directly driven, the device output characteristics given in the published data should be consulted to determine the requirements for a safe operation below 200 milliwatts.

For detailed COS/MOS IC operating and handling considerations, refer to Application Note ICAN-6000 "Handling and Operating Considerations for MOS Integrated Circuits".

SOLID STATE CHIPS

Solid state chips, unlike packaged devices, are non-hermetic devices, normally fragile and small in physical size, and therefore, require special handling considerations as follows:

1. Chips must be stored under proper conditions to insure that they are not subjected to a moist and/or contaminated atmosphere that could alter their electrical, physical, or mechanical characteristics. After the shipping container is opened, the chip must be stored under the following conditions:
   - A. Storage temperature, 40°C max.
   - B. Relative humidity, 50% max.
   - C. Clean, dust-free environment.
2. The user must exercise proper care when handling chips to prevent even the slightest physical damage to the chip.
3. During mounting and lead bonding of chips the user must use proper assembly techniques to obtain proper electrical, thermal, and mechanical performance.
4. After the chip has been mounted and bonded, any necessary procedure must be followed by the user to insure that these non-hermetic chips are not subjected to moist or contaminated atmosphere which might cause the development of electrical conductive paths across the relatively small insulating surfaces. In addition, proper consideration must be given to the protection of these devices from other harmful environments which could conceivably adversely affect their proper performance.

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*Mil-M-38510A, paragraph 3.5.6.1 (a), lead material.

RCA
Solid State
Division

Thyristors
Application Note
AN-3418

Design Considerations for the RCA-S6431M Silicon Controlled Rectifier In High-Current Pulse Applications

by

D. E. Burke and G. W. Albrecht

Silicon controlled rectifiers (SCR's) are often used in pulse circuits in which the ratio of peak to average current is large. Typical applications include radar pulse modulators, inverters, and switching regulators. The limiting parameter in such applications often is the time required for forward current to spread over the whole area of the junction. Losses in the SCR are high, and are concentrated in a small region until the entire junction area is in conduction. This concentration produces undesirable high temperatures.

The RCA-S6431M SCR is specially designed to achieve rapid utilization of the full junction area. The rating curves and calculations presented in this Note allow the designer to make full use of the high switching capability of this device.

Circuits

A typical SCR pulse modulator circuit is shown n Fig.1. Basic waveforms for the circuit are shown n Fig.2. The capacitors of the energy-storage network re charged by the dc supply. The SCR is triggered y pulses from the gate-trigger generator No. 1, and the nergy-storage network discharges through an inductnce and the load (transformer). Fig.2 shows that the lischarge of the storage network ($t_1 - t_2$) is oscillatory; he half-sine-wave shape is characteristic of a single LC-section energy-storage network.

For turn-off, the load is "mismatched" to the ischarge-circuit impedance so that a negative voltage s developed on the capacitor at the end of the pulse. The negative voltage reverse-biases the SCR. This form of turn-off is indicated in Fig.2(b).

When the energy-storage network is recharged from the dc supply, the SCR returns to the forward-blocking condition and is ready for the next cycle. The recharge interval (t_3 - t_4) may be delayed by use of a charging SCR, as shown in Figs.1 and 2 (t_2 - t_3). This technique reduces the turn-off time requirements for the SCR. The rate of recharge influences the dv/dt requirements for the SCR.

Figs.1 and 2 illustrate only one of a great variety of pulse circuits, each of which would have particular requirements for the SCR. A common requirement would be to pass forward currents with particular emphasis on shape and magnitude.

Turn-On Time Definitions

In the idealized waveforms of Fig.2, the SCR is presented as a perfect switch. Actually, it exhibits a finite resistance prior to turn-on, a delay after the introduction of the trigger pulse, and appreciable resistance after turn-on.

The common definition of turn-on time adequately covers the delay and rise-time intervals of the turn-on process, but does not consider the rate of current spread over the junction area and its attendant dissipation. Because the dissipation after turn-on is an important consideration in pulse circuits, turn-on definitions in themselves provide no indication of the switching capability of the SCR.

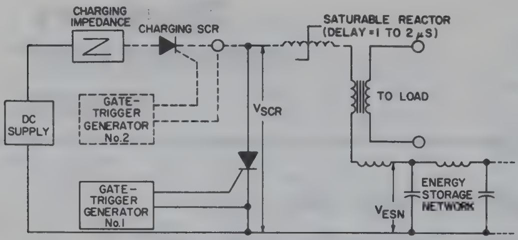
CHARGING IMPEDANCE
Z
CHARGING SCR
SATURABLE REACTOR (DELAY = 1 TO 2 μS)
TO LOAD
DC SUPPLY
GATE-TRIGGER GENERATOR No.2
VSCR
GATE-TRIGGER GENERATOR No.1
ENERGY STORAGE NETWORK
VESN

Fig.1 - Basic pulse modulator circuit.

As an example, the rise-time portion of turn-on is defined as the time interval between the 10-per-cent and 90-per-cent points on the current wave shape when the SCR is triggered on in a circuit that has rated forward voltage and sufficient resistance to limit the current to rated values. For a 600-volt device, the end of the turn-on interval occurs when the forward voltage drop across the SCR is 60 volts. This value contrasts with the steady-state forward voltage of only 1 or 2 volts under such conditions. An interval many times greater than the turn-on time may be required before the forward voltage drop reduces to the steady-state level.

Switching Capability

Because several different physical effects occur in the SCR during the complete turn-on interval, it is convenient to divide the total turn-on time into three discrete intervals: delay time t_1, fall time t_2, and equalizing time t_3. These intervals are shown in Fig.3. The solid lines represent device turn-on to low steady-state forward current, in which case equalization effects are not pronounced. The dashed lines represent SCR turn-on to high currents, in which case t_3 becomes a noticeable interval.

The first interval (t_1 or delay time) results from the initiation of forward conduction between the p-type base and the n-type emitter (i.e., injection of holes through the gate-cathode junction and injection of electrons through the cathode-gate junction). This interval depends to a large extent upon the level of gate current used to turn on the SCR. The use of a trigger pulse greater than the minimum gate-current requirement of the SCR minimizes delay time and reduces the range of the delay times encountered between individual SCR's, the variability of delay with temperature, and the variability of cycle-to-cycle delay or jitter.* There are no significant power losses in the SCR during delay. The delay interval is primarily of interest because of its effect on system performance.

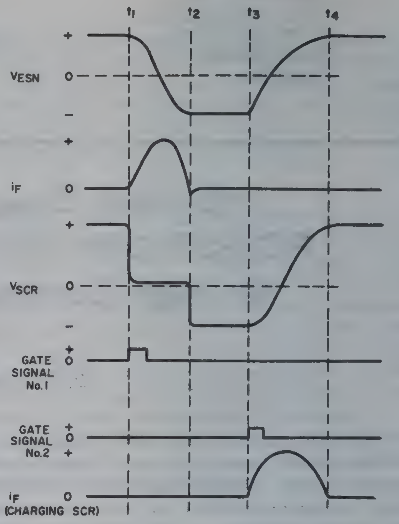
t1
t2
t3
t4
VESN
+
0
-
iF
VSCR
GATE SIGNAL No.1
GATE SIGNAL No.2
iF (CHARGING SCR)

Fig.2 - Idealized waveforms for pulse-discharge circuit.

The second interval (t_2 or fall time) depends on the initiation of forward conduction between the p-type emitter and the n-type emitter (i.e., anode-to-cathode current). When this phenomenon is isolated from current effects, as described later, the duration of the voltage fall time measured from the 90-per-cent to the 10-per-cent point is less than 0.3 microsecond. Voltage fall time is illustrated in Fig.4 for a range of initial voltages.

The flow of forward current during the voltage fall time results in power loss in this interval. The magni-

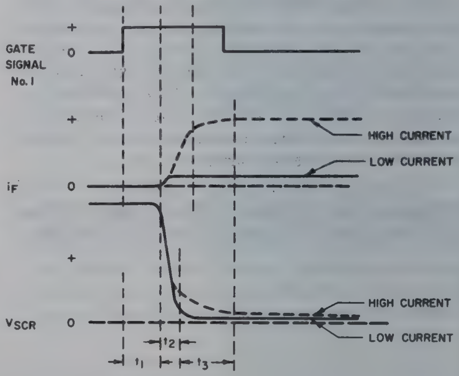
GATE SIGNAL No.1
+
0
iF
HIGH CURRENT
LOW CURRENT
VSCR
HIGH CURRENT
LOW CURRENT
t2
t1
t3

Fig.3 - Actual SCR wave shapes during turn-on.

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* The technical bulletin for the S6431M contains information on maximum trigger-pulse magnitudes for various pulse widths for this device. This Note discusses gating characteristics of RCA SCR's in more detail.

tude of this loss is primarily determined by the response of the circuit to the voltage fall waveshape. If the rate of current rise desired by the circuit is faster than the fall time of voltage in the SCR, the device experiences high peak dissipation during the short turn-on interval.

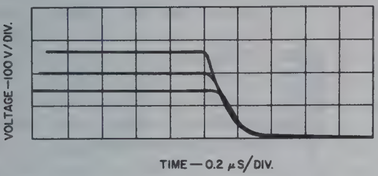


Fig.4 - Illustration of voltage fall time (low forward current).

The third discrete interval during turn-on, equalization time (t_3 of Fig.3), represents the time required for the current to spread over the junction area. The forward current resulting from the initial voltage fall is concentrated in a small area of the junction and spreads gradually over the entire area. The rate of increase in the active junction area depends on the geometry and the junction parameters, and is influenced by the levels of driving voltage and current. In general, the time required for full utilization of junction area represents a considerably longer interval than t_1 (delay) or t_2 (fall).

For given conditions of current rise time, current level, and gate drive, t_3 could be defined as the time required for forward voltage to decrease to a given multiple of the final steady-state value under a constant-current pulse. Such a definition would be more indicative of switching capability than the conventional definition of turn-on time as the time required for forward ON-state voltage to decrease to a percentage of the initial blocking voltage. At best, however, either type of definition has only limited usefulness to the user.

Characteristics and Ratings

Because the major factor in the rating of SCR's for pulse applications is the initial forward-voltage drop, the RCA-S6431M is rated specifically for this characteristic. Figs.5 and 6 show two families of rating curves which make it possible to calculate the power loss per pulse and the average power loss for a particular current-pulse shape, magnitude, and repetition rate desired. Figs.7 and 8 show maximum allowable repetition rates and pulse amplitudes for several pulse shapes, and are useful as a quick estimating guide for the pulse-current switching capability of the S6431M SCR.

Limits must also be imposed upon the instantaneous temperature rise of the junction over the average case temperature and upon the differential temperature stresses in the device. Fig.9 shows the allowable maximum current for the S6413M at any time after the initiation of the current pulse. This curve, together with those in Figs.7 and 8, gives an indication of the feasibility of using the S6431M in a high-current pulse application.

Fig.10 illustrates the calculation of device dissipation and pulse repetition rate for a particular pulse

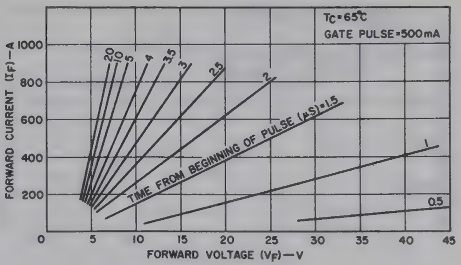


Fig.5 - Forward voltage as a function of forward voltage at various times after the initiation of turn-on.

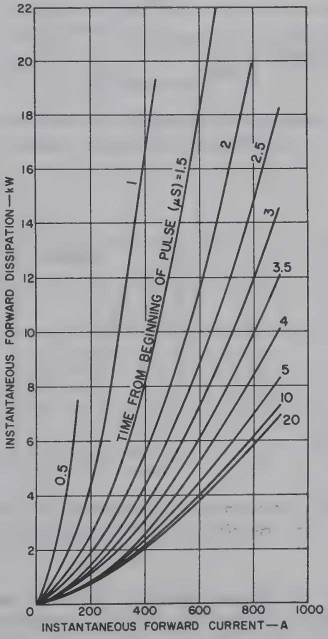


Fig.6 - Instantaneous forward dissipation as a function of current at various times after the initiation of turn-on.

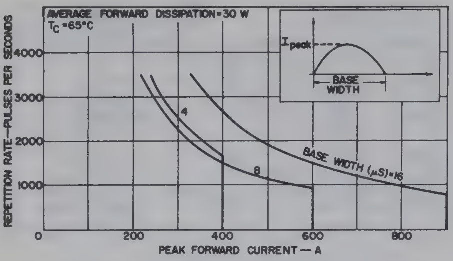


Fig.7 - Peak current as a function of maximum repetition rate for sine-wave pulse shapes.

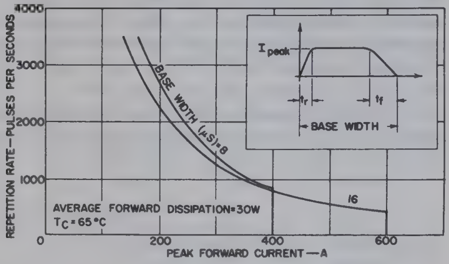


Fig.8 - Peak current as a function of maximum repetition rate for square-wave pulse shapes.

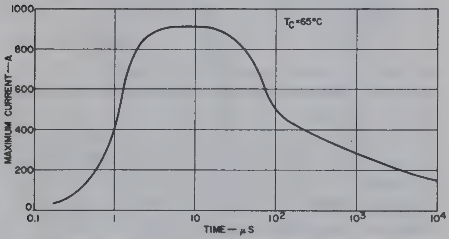
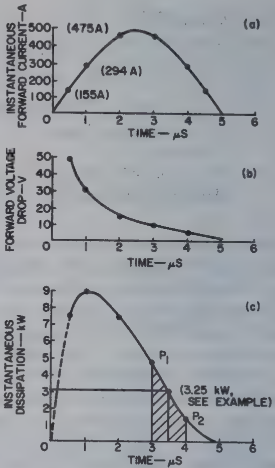


Fig.9 - Maximum permissible current as a function of time after the initiation of turn-on.

shape. In the example shown, the pulse has a peak magnitude of 500 amperes and a base width of 5 microseconds. The curves shown in Fig.10 are constructed from the curves of Figs.5 and 6 by means of a series of readings at different time intervals (delay and fall regions are neglected). A step-by-step approximate integral approach is then used to obtain the watt-seconds-per-pulse measurements shown in the table. For a repetition rate of 1000 pulses per second, the average forward dissipation is 24.37 watts for the current pulse specified. This value is within the rating of 30 watts for the S6431M at a case temperature of 65°C. At higher case temperatures the total dissipation must be decreased, as shown in Fig.11.



(d)

TIME INTERVAL (μS)	DISSIPATION FOR INTERVAL mW-S	TOTAL DISSIPATION FOR ONE PULSE mW-S	AVERAGE DISSIPATION AT 1000 C/S REP. RATE (W)	MAXIMUM REP. RATE FOR 30W DISSIPATION (C/S)
0—0.5	1.87	24.37	24.37	1225
0.5—1	4.12			
1—2	8.25			
2—3	6.18			
3—4	3.25			
4—5	0.70			

EXAMPLE: AVERAGE FORWARD WATT-SECOND DISSIPATION DURING 3μS TO 4μS INTERVAL:
$(4-3) \times 10^{-6}$ S $\times 3.25 \times 10^3$ W $= 3.25$ mW-S

Fig.10 - Sample calculation of forward dissipation.

Because the interval of highest dissipation occurs at the beginning of the current pulse, reduction in the magnitude of current during this time increases the over-all switching capability of the SCR. The current may be reduced by use of a saturable reactor in the pulse-discharge circuit which has sufficient unsaturated volt-second capacity to present a high impedance for one to two microseconds. The current is then small, and dissipation is limited, until the junction area in conduction increases to include an appreciable percentage of the total cathode. By the time the reactor saturates and high pulse current results, the cathode area in conduction is adequate to handle the high current with low dissipation.

The rate of current spread over the cathode area depends upon several factors, one of which is the level of current. Therefore, the use of a delay reactor to keep forward current low also delays the spread of current to some extent and subtracts from its beneficial effects. The maximum benefit can be achieved by reduction of the inductance of the reactor prior to saturation, or by addition of another impedance in parallel with the reactor, to effect a compromise between the initial current level and dissipation and the rate of current-density equalization. The curves in this Note do not represent the use of a delay reactor.

In addition to the power loss in the SCR caused by forward current, the total dissipation in the device includes forward and reverse blocking losses and probably reverse recovery losses during the turn-off process. The reverse recovery losses depend upon several factors, such as forward-current amplitude, rate of decrease of forward current, reverse-current flow, rate of rise of reverse voltage, and reverse-voltage amplitude. Because reverse losses are circuit-dependent, they can best be evaluated in a working circuit.

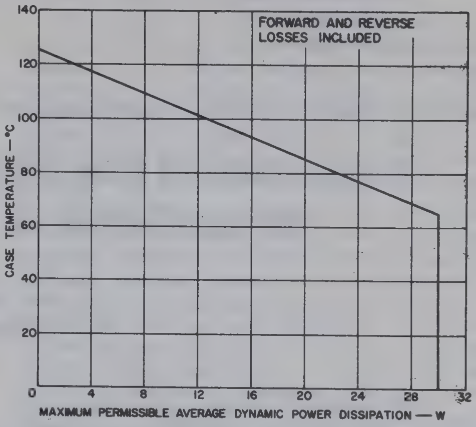


Fig.11 - Maximum average total power dissipation as a function of case temperature.

RCA
Solid State
Division

Thyristors
Application Note
AN-3469

Application of RCA Silicon Controlled Rectifiers to the Control of Universal Motors

by
J.V. Yonushka

Silicon controlled rectifiers have been widely accepted in power-control applications in industrial systems where high-performance requirements justify the economics of the application. Historically, in the commercial high-volume market, economic considerations have precluded the use of the SCR. However, with the development of a family of SCR's by RCA designed specifically for mass-production economy and rated for 120- and 240-volt line operation, the use of these devices in controls for many types of small electric motors has been made economically feasible. The controls can be designed to provide good performance, maximum efficiency, and high reliability in compact packaging arrangements.

The control circuits discussed in the following text are typical of the many possible circuits applicable to electric motor control. A general description including the typical characteristics of universal motors is given. Speed control by use of phase-angle variations is discussed; schematic diagrams are given, and the advantages and limitations of each circuit are contrasted. A chart of available SCR's is shown at the end of the Note.

Universal Motors

Many fractional horsepower motors are series-wound "universal" motors, so named because of their ability to operate directly from either ac or dc power sources. Fig.1 is a schematic of this type of motor operated from an ac supply. Because most domestic applications today require 60-hertz power, universal motors are usually designed to have optimum performance characteristics at this frequency. Most universal motors run faster at a given dc voltage than at the same 60-hertz ac voltage.

The field winding of a universal motor, whether distributed or lumped (salient pole), is in series with the armature and external circuit, as shown in Fig.1.

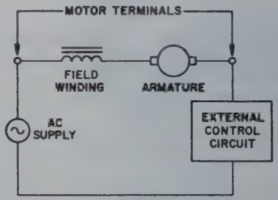


Fig.1 - Schematic diagram for a series-wound universal motor.

The current through the field winding produces a magnetic field which cuts across the armature conductors. The action of this field in opposition to the field set up by the armature current subjects the individual conductors to a lateral thrust which results in armature rotation.

AC operation of a universal motor is possible because of the nature of its electrical connections. As the ac source voltage reverses every half-cycle, the

11-73

magnetic field produced by the field winding reverses its direction simultaneously. Because the armature windings are in series with the field windings through the brushes and commutating segments, the current through the armature winding also reverses. Because both the magnetic field and armature current are reversed, the direction of the lateral thrust on the armature windings remains constant.

As the armature rotates through the magnetic field, a voltage opposite to the impressed voltage is induced in the individual conductors. Counter emf produced in the armature conductors is therefore proportional to motor speed. In half-wave operation, during the non-conducting half-cycle of an SCR, the rotating armature still produces a counter emf because of the residual magnetism of the field poles. In some of the applications described, the counter emf of an operating motor is used as a means of providing speed regulation to compensate for changing shaft loads.

The current through an operating motor armature depends upon the difference between the impressed voltage (emf) and the counter emf. The current that flows through a universal motor when it is initially energized is large because there is no rotation to generate a counter emf in the armature windings. The starting current is limited only by the impedance of the armature and field windings. The ratio of peak starting current to peak running current can be as high as 10:1.

The speed of a series motor automatically adjusts itself so that the difference between the impressed voltage and the counter emf is sufficient to permit enough current to flow to develop the torque required by the load. At very light loads, or at no load, the current through a universal motor is small. To maintain a small current through the motor, the counter emf must be high enough so that only a small difference exists between the impressed voltage and the counter emf. The small current through the motor also results in a weak magnetic-field flux because it is the current through the field winding that produces the flux. The weakened magnetic-field flux tends to make the motor speed increase even further to produce the high counter emf required to maintain a small motor current. It would appear, then, that universal motors should tend to "run away" at no load. This run-away does not occur, however, because motors of this type usually offer enough friction and windage loss to limit the maximum attainable no-load speed to a safe value.

When a mechanical load is attached to a universal motor, the current through the motor must increase to provide the increased torque required by the load. An increase in the current through the motor requires an increase in the difference between the impressed voltage and the counter emf. This increased difference can only be brought about by a reduction in counter emf derived from a decrease in speed. For an uncompensated universal motor, the full-load speed is approximately 60 per cent or less of the no-load speed.

The torque developed by a universal motor is a direct result of the magnitude of magnetic-field flux and armature current. For fixed mechanical loads, the starting torque of a universal motor is high because the armature current at starting time is high; at "stall" conditions, because of the large armature current, the torque is again high. The stall torque of a series motor can be as high as 10 times the continuous rated torque.

Because torque and armature current influence the speed of a universal motor, it is possible under certain operating conditions to vary the impressed voltage and influence operating characteristics of the motor. For increased mechanical loads, an increase in the impressed voltage produces a larger armature current and tends to keep the speed constant. High starting torque, adjustable speed characteristics, and small size are distinct advantages of a universal motor over a comparably rated single-phase induction motor. Typical performance characteristic curves for a universal motor are shown in Fig.2.

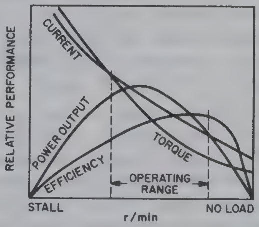


Fig.2 - Typical performance curves for a universal motor.

Use of Silicon Controlled Rectifiers for Motor Control

One of the simplest and most efficient means of varying the impressed voltage to a load on an ac power system is by control of the conduction angle of an SCR placed in series with the load. Typical curves showing the variation of motor speed with SCR conduction angle for both half-wave and full-wave impressed motor voltages are illustrated in Fig.3. If desired, a switch may be installed in the half-wave circuits so that the SCR and its related control circuit can be bypassed for full-power operation.

Half-Wave Control

There are many good circuits available for half-wave control of universal motors; their attributes and limitations are described in detail below. The circuits are divided into two classes; regulating and non-regulating. Regulation in this instance implies load sensing and compensation of the system to prevent changes in

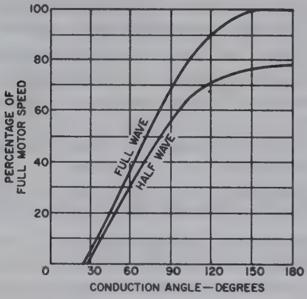
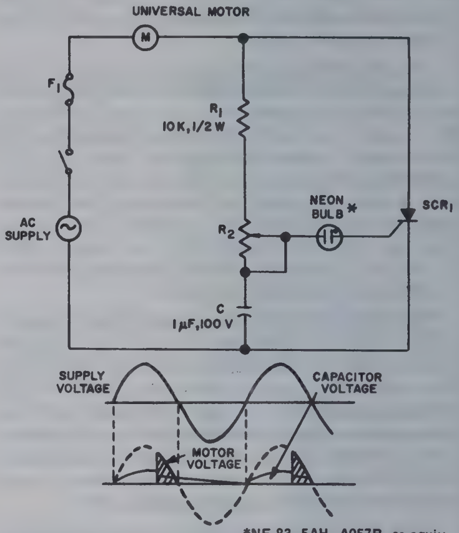


Fig.3 - Typical performance curves for a universal motor with phase-angle control.

motor speed. The type of regulation provided by each circuit is stated and compared to other circuits.

The half-wave proportional control circuit shown in Fig.4 is a non-regulating circuit whose function depends upon an RC delay network for gate phase-lag control. This circuit is better than simple resistance firing circuits because the phase-shifting characteristics of the RC network permit the firing of the SCR beyond the peak of the impressed voltage, resulting in small conduction angles and very slow speed.

The control circuit shown in Fig.4 uses the breakdown voltage of a neon lamp as a threshold setting for firing the SCR. The neon lamp is specifically designed for handling the high-current pulses required to trigger SCR's. When the voltage across capacitor C reaches the breakdown voltage of the neon lamp, the lamp fires, and C discharges through the lamp to its maintaining voltage. At this point, the lamp again reverts to its high-impedance state. The discharge of the capacitor from breakdown to maintaining voltage of the neon lamp provides a current pulse of sufficient magnitude to fire the SCR. Once the SCR has fired, the voltage across the phase-shift network reduces to the forward voltage drop of the SCR for the remainder of the half-cycle. The range of conduction angles of this circuit is approximately 30 to 150 degrees. The high breakdown voltage of the neon lamp improves noise rejection and prevents erratic firing of the SCR because of brush noises on the voltage supply lines. Table I shows components for the circuit of Fig.4.



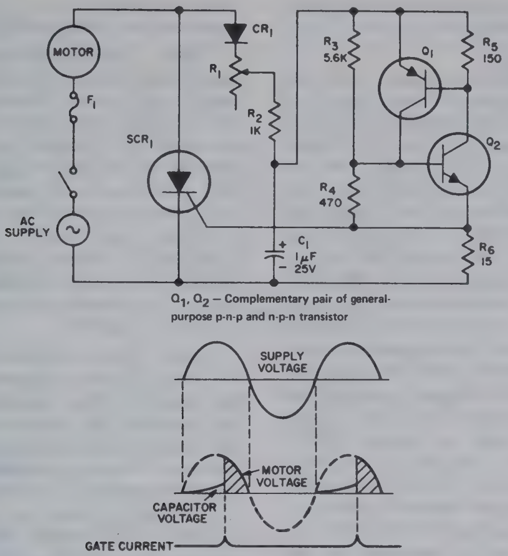
*NE-83, 5AH, A057B, or equiv.

Fig.4 - Half-wave motor control with no regulation.

The circuit shown in Fig.5 reduces spread in gate turn-on characteristics. This circuit depends upon the fast switching characteristics of transistors such as those used in the two-transistor regenerative trigger network shown. The phase-shift characteristics are still retained to provide conduction angles less than 90 degrees through the RC network of R_1, R_2, and C_1. Resistor R_3 provides turn-on current to the base of Q_1 when the voltage across C_1 becomes large enough during the positive half-cycle. The base current in Q_1 turns on this transistor. Transistor Q_1 then supplies base

TABLE I - COMPONENTS FOR CIRCUIT SHOWN IN FIG.4.

AC SUPPLY	AC CURRENT	F_1	CR_1	R_2	SCR_1
120 V	1 A	3 AG, 1.5 A, Quick Act	D1201B	100 K, 1/2 W	RCA-2N3528
120 V	3 A	3 AB, 3 A	D1201B	100 K, 1/2 W	RCA-2N3228
120 V	7 A	3 AB, 7 A	D1201B	100 K, 1/2 W	RCA-2N3669
240 V	1 A	3 AG, 1.5 A, Quick Act	D1201D	150 K, 1/2 W	RCA-2N3529
240 V	3 A	3 AB, 3 A	D1201D	150 K, 1/2 W	RCA-2N3525
240 V	7 A	3 AB, 7 A	D1201D	150 K, 1/2 W	RCA-2N3670


MOTOR
F_1
AC SUPPLY
SCR_1
CR_1
R_1
R_2 1K
R_3 5.6K
R_4 470
C_1 1 μF 25V
Q_1
Q_2
R_5 150
R_6 15
SUPPLY VOLTAGE
MOTOR VOLTAGE
CAPACITOR VOLTAGE
GATE CURRENT

Q_1, Q_2 – Complementary pair of general-purpose p-n-p and n-p-n transistor

Fig.5 - Half-wave motor control with no regulation.

current to Q_2. When Q_2 turns on, it supplies more base current to Q_1. This regenerative action leads to the rapid saturation of transistors Q_1 and Q_2. Capacitor C_1 discharges through the saturated transistors into the gate of the SCR. When the SCR fires, the remaining portion of the positive half-cycle of ac power is applied to the motor. Speed control is accomplished by adjustment of potentiometer R_1. With component values as shown on the schematic diagram in Fig.5, the threshold voltage for firing the circuit is approximately 8 volts; the maximum conduction angle is approximately 170 degrees. Table II shows components for the circuit with various RCA SCR's.

Fig.6 shows a fundamental circuit of direct-coupled SCR control with voltage feedback. This circuit is highly effective for speed control of universal motors. The circuit makes use of the counter emf (cemf) induced

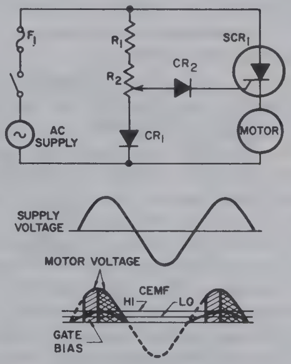

F_1
R_1
R_2
CR_2
SCR_1
AC SUPPLY
CR_1
MOTOR
SUPPLY VOLTAGE
MOTOR VOLTAGE
CEMF
HI
LO
GATE BIAS

Fig.6 - Half-wave motor control with regulation.

TABLE II - COMPONENTS FOR CIRCUIT SHOWN IN FIG.5.

AC SUPPLY	AC CURRENT	F_1	CR_1	R_1	SCR_1
120 V	1 A	3 AG, 1.5 A, Quick Act	D1201B	75 K, 1/2 W	RCA-2N3528
120 V	3 A	3 AB, 3 A	D1201B	75 K, 1/2 W	RCA-2N3228
120 V	7 A	3 AB, 7 A	D1201B	75 K, 1/2 W	RCA-2N3669
240 V	1 A	3 AG, 1.5 A, Quick Act	D1201D	150 K, 1/2 W	RCA-2N3529
240 V	3 A	3 AB, 3 A	D1201D	150 K, 1/2 W	RCA-2N3525
240 V	7 A	3 AB, 7 A	D1201D	150 K, 1/2 W	RCA-2N3670

in the rotating armature because of the residual magnetism in the motor on the half-cycle when the SCR is blocking.

The counter emf is a function of speed and, therefore, can be used as an indication of speed changes as mechanical load varies. The gate-firing circuit is a resistance network consisting of R_1 and R_2. During the positive half-cycle of the source voltage, a fraction of the voltage is developed at the center-tap of the potentiometer and is compared with the counter emf developed in the rotating armature of the motor. When the bias developed at the gate of the SCR from the potentiometer exceeds the counter emf of the motor, the SCR fires. AC power is then applied to the motor for the remaining portion of the positive half-cycle. Speed control is accomplished by adjustment of potentiometer R_1. If the SCR is fired early in the cycle, the motor operates at high speed because essentially the full rated line voltage is applied to the motor. If the SCR is fired later in the cycle, the average value of voltage applied to the motor is reduced, and a corresponding reduction in motor speed occurs. On the negative half-cycle, the SCR blocks voltage to the motor. The voltage applied to the gate of the SCR is a sine wave because it is derived from the sine-wave line voltage. The minimum conduction angle occurs at the peak of the sine wave and is restricted to 90 degrees. Increasing conduction angles occur when the gate bias to the SCR is increased to allow firing at voltage values which are less than the peak value.

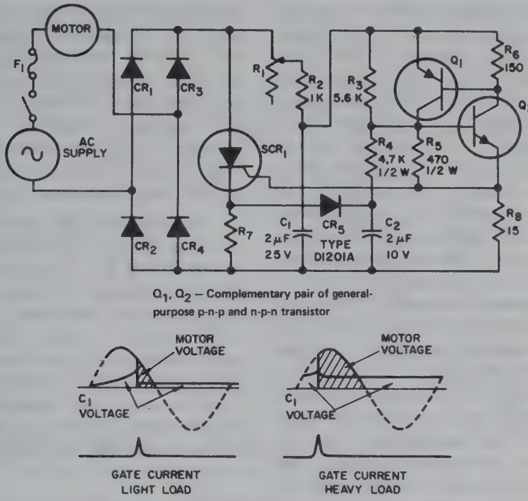
At no load and at the low-speed control setting, "skip-cycling" operation occurs, and motor speeds are erratic. Because no counter emf is induced in the armature when the motor is standing still, the SCR fires at low bias settings. The motor is then accelerated to a point at which counter emf induced in the rotating armature exceeds the gate-firing bias of the SCR and prevents the SCR from firing. The SCR is not able to fire again until the speed of the motor is reduced (because of friction and windage losses) to a value for which the induced voltage in the rotating armature is less than the gate bias. At this time the SCR fires again. The motor deceleration occurs over a number of cycles when there is no voltage applied to the motor, (hence the term "skip cycling").

When a load is applied to the motor, the motor speed decreases and thus reduces the counter emf induced in the rotating armature. With a reduced counter emf, the SCR fires earlier in the cycle and provides increased motor torque to the load. Fig.6 also shows variations of conduction angle with changes in counter emf. The counter emf appears as a constant voltage at the motor terminals when the SCR is blocking. Because the counter emf is essentially a characteristic of the motor, different potentiometer settings are required for comparable operating conditions for different motors. Circuit values for use with various RCA SCR's are shown in Table III.

Fig.7 shows a variation of the circuit in Fig.5. The basic difference between the two circuits is that the circuit in Fig.7 provides feedback for changing load conditions to minimize changes in motor speed. The feedback is provided by R_7, which is in series with the motor. A voltage proportional to the peak current through the motor is developed across the resistor. This voltage is stored on capacitor C_2 through diode CR_2, and is of a polarity that causes the bias on the resistance network of R_3 and R_4 to change in accordance with the load on the motor. With an increasing motor load, the speed tends to decrease. This decrease in motor speed causes more current to flow through the motor armature and field windings. When the current flowing through R_7 increases, the voltage stored on capacitor C_2 increases in the positive direction. This increase in capacitor voltage causes the transistors to conduct earlier in the cycle, to fire the SCR, and to provide a greater portion of the power cycle to the motor. With a decreasing load, the motor current decreases and the voltage stored by capacitor C_2 decreases. The transistors and SCR then conduct later in the cycle. The resultant reduction in the average power supplied to the motor causes a reduced torque to the smaller load. Because motor current is a function of the motor itself, resistor R_7 has to be matched with the motor rating to provide optimum feedback for load compensation. Resistor R_7 may range from 0.1 ohm for

TABLE III - COMPONENTS FOR CIRCUIT SHOWN IN FIG.6.

AC SUPPLY	AC CURRENT	F_1	CR_1, CR_2	R_1	R_2	SCR_1
120 V	1 A	3 AG, 1.5 A, Quick Act	D1201B	5.6 K, 2 W	1 K, 2 W	RCA-2N3528
120 V	3 A	3 AB, 3 A	D1201B	5.6 K, 2 W	1 K, 2 W	RCA-2N3228
120 V	7 A	3 AB, 7 A	D1201B	2.7 K, 4 W	500, 2 W	RCA-2N3669
240 V	1 A	3 AG, 1.5 A, Quick Act	D1201D	10 K, 5 W	1 K, 2 W	RCA-2N3529
240 V	3 A	3 AB, 3 A	D1201D	10 K, 5 W	1 K, 2 W	RCA-2N3525
240 V	7 A	3 AB, 7 A	D1201D	5.6 K, 7.5 W	500, 2 W	RCA-2N3670


MOTOR
F1
AC SUPPLY
CR1
CR3
CR2
CR4
R1
R2 1K
R3 5.6 K
R4 4.7 K 1/2 W
R5 470 1/2 W
R6 150
R7
R8 15
SCR1
Q1
Q2
C1 2 μF 25 V
CR5 TYPE D1201A
C2 2 μF 10 V
MOTOR VOLTAGE
C1 VOLTAGE
GATE CURRENT LIGHT LOAD
MOTOR VOLTAGE
C1 VOLTAGE
GATE CURRENT HEAVY LOAD

Q_1, Q_2 – Complementary pair of general-purpose p-n-p and n-p-n transistor

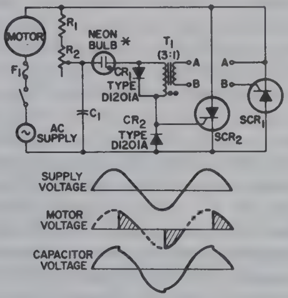
Fig.7 - Half-wave motor control using two-transistor regenerative triggering with regulation.

larger-size universal motors to 1.0 ohm for smaller types. Circuit values for use with various RCA SCR's are shown in Table IV.

Full-Wave Control

This section discusses the application of SCR's to full-wave motor control. Two SCR's are usually required to provide full-wave control.

A very simple SCR full-wave proportional control circuit is shown in Fig.8. Again, ac phase shifting and neon triggering are used to provide gate phase-angle control; a small pulse transformer is utilized for isolation. The circuit provides a symmetrical output for both halves of the ac input voltage because the same electrical components are used in the phasing network for both SCR gates. Because the SCR gate circuits are completely isolated from each other, the cross-talk problem usually associated with gate firing circuits using transformer coupling and bi-directional trigger devices is avoided. There is a hysteresis effect associated with this circuit because C_1 charges to alternate positive and negative values. As R_2 decreases from


MOTOR
F1
AC SUPPLY
R1
R2
NEON BULB *
T1 (3:1)
A
B
A
B
CR1 TYPE D1201A
C1
CR2 TYPE D1201A
SCR1
SCR2
SUPPLY VOLTAGE
MOTOR VOLTAGE
CAPACITOR VOLTAGE

*NE-83, 5AH, A057B, or equiv.
T_1 - Better Coil and Transformer Co. Type 99A16, or equiv.

Fig.8 - Full-wave motor control with no regulation.

TABLE IV - COMPONENTS FOR CIRCUIT SHOWN IN FIG.7.

AC SUPPLY	AC CURRENT	F_1	CR_1	R_1	SCR_1
120 V	1 A	3 AG, 1.5 A, Quick Act	D1201B	75 K, 1/2 W	RCA-2N3528
120 V	3 A	3 AB, 3 A	D1201B	75 K, 1/2 W	RCA-2N3228
120 V	7 A	3 AB, 7 A	D1201B	75 K, 1/2 W	RCA-2N3669
240 V	1 A	3 AG, 1.5 A, Quick Act	D1201D	150 K, 1/2 W	RCA-2N3529
240 V	3 A	3 AB, 3 A	D1201D	150 K, 1/2 W	RCA-2N3525
240 V	7 A	3 AB, 7 A	D1201D	150 K, 1/2 W	RCA-2N3670

its maximum value, C_1 charges to a higher voltage on each half cycle. When the positive half-cycle voltage on C_1 reaches the breakdown potential of the neon lamp, the lamp fires, allowing C_1 to discharge to the maintaining voltage of the lamp through CR_1 and the lamp into the gate of SCR_2. When SCR_2 fires, the voltage across the control circuit drops to the forward voltage value of the SCR, allowing C_1 to discharge. On the next half-cycle, C_1 charges from a lower positive potential and allows the neon lamp to fire earlier in the cycle. If the potentiometer resistance R_2 is increased, the SCR's fire at a reduced conduction angle and the hysteresis effect is produced. On the negative half-cycle, when the charge on C_1 has reached the breakdown potential of the neon lamp, the capacitor discharges through CR_2, the lamp, and the primary of transformer T_1 to the maintaining voltage of the neon lamp. The current pulse formed by the discharge of C_1 is coupled by T_1 into the gate of SCR_1. For 60-hertz operation, the transformer characteristics are not critical because the magnitude and shape of the current firing pulse are determined primarily by the charge on the capacitor and the characteristics of the neon lamp. Circuit values for use with various RCA SCR's are shown in Table V. Conduction angles obtained with this circuit vary from 30 to 150 degrees; at the maximum conduction angle, the voltage impressed upon the load (universal motor) is approximately 95 per cent of the input rms voltage.

Fig.9 shows a full-wave control circuit that has increased conduction-angle capability. Table VI shows the component chart for use of the circuit with various SCR's. The threshold point of the transistor circuit can be changed by varying the value of R_3. The phase-shift network composed of R_1, R_2, and C_1 permits the variation of conduction angles from minimum to maximum. An ac potential impressed upon this phase-shifting network eliminates skip-cycling at low conduction angles. The bridge network of CR_1, CR_2, CR_3, and CR_4 rectifies the ac voltage developed across C_1 and provides the switching transistors with dc voltage. When the switching transistors are on and saturated, capacitor C_1 discharges through them into the primary of T_1. Because both SCR's receive the same gate polarity pulse, the pulse formed by C_1 and T_1 fires that SCR with a positive potential at the anode. When the SCR fires, the remaining portion of the half-cycle is applied to the load. On the alternate half-cycle, the other SCR turns on. With the component values shown in Fig.9, the threshold voltage required to fire the transistor circuit is approximately 8 volts. Variations in conduction angle are accomplished by changing the setting of R_2. In this circuit, the conduction angles may be varied from 5 to 170 degrees; this larger range is more desirable when higher power is to be controlled.

An SCR full-wave circuit designed for applications requiring feedback for compensation of load changes is shown in Fig.10. Operation is similar to that of the circuits discussed previously except that this circuit has full-wave conduction with proportional control. Again, as in the circuit of Fig.7, R_7 must be matched with the motor rating to provide optimum feedback for load compensation. Resistor R_7 may range from 0.1 ohm for larger-size universal motors to 1.0 ohm for smaller types. Table VII gives a component list for use of this circuit with various SCR's.

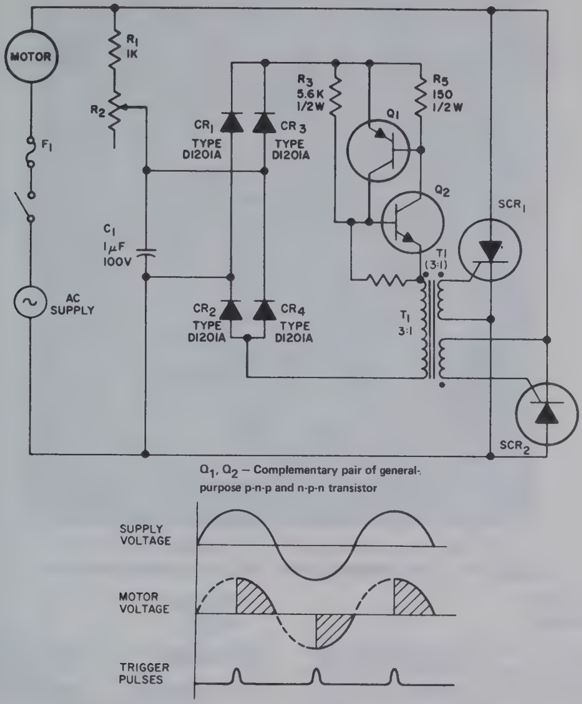
Ratings and Limitations

Package size and environment limit the voltage and current capabilities and, consequently, the power-dissipation abilities of an SCR. Maximum temperature ratings usually depend on the use of a heat sink of a particular size at a prescribed ambient or case temperature.

The main cause of heat within an SCR operating at 60 hertz is the forward current and voltage drop during conduction. Under steady-state conditions, the heat generated within the device must be balanced by the flow of heat to the heat sink and the ambient air. If more heat is generated within the SCR than can be dissipated by the case and the heat sink, the junction temperature increases and forward blocking capabilities are lost. Under these conditions the SCR may break down thermally in the reverse direction, causing damage to the SCR pellet. An increase in heat-sink size to maintain the balance between heat generated and heat dissipated assures reliable performance of the SCR.

TABLE V - COMPONENTS FOR CIRCUIT SHOWN IN FIG.8.

AC SUPPLY	AC CURRENT	F_1	R_1	R_2	C_1	SCR_1, SCR_2
120 V	1.5 A	3 AG, 2 A, Quick Act	1 K, 1/2 W	50 K, 1/2 W	0.22 μF, 100 V	RCA-2N3528
120 V	5 A	3 AB, 5 A	1 K, 1/2 W	50 K, 1/2 W	0.22 μF, 100 V	RCA-2N3228
120 V	10 A	3 AB, 10 A	1 K, 1/2 W	25 K, 2 W	0.47 μF, 100 V	RCA-2N3669
240 V	1.5 A	3 AG, 2 A, Quick Act	1 K, 1 W	50 K, 2 W	0.22 μF, 100 V	RCA-2N3529
240 V	5 A	3 AB, 5 A	1 K, 1 W	50 K, 2 W	0.22 μF, 100 V	RCA-2N3525
240 V	10 A	3 AB, 10 A	1 K, 1 W	25 K, 4 W	0.47 μF, 100 V	RCA-2N3670


MOTOR
F1
AC SUPPLY
R1 1K
R2
C1 1μF 100V
CR1 TYPE D1201A
CR3 TYPE D1201A
CR2 TYPE D1201A
CR4 TYPE D1201A
R3 5.6K 1/2W
R5 150 1/2W
Q1
Q2
T1 (3:1)
T1 3:1
SCR1
SCR2
SUPPLY VOLTAGE
MOTOR VOLTAGE
TRIGGER PULSES

Q_1, Q_2 – Complementary pair of general-purpose p-n-p and n-p-n transistor

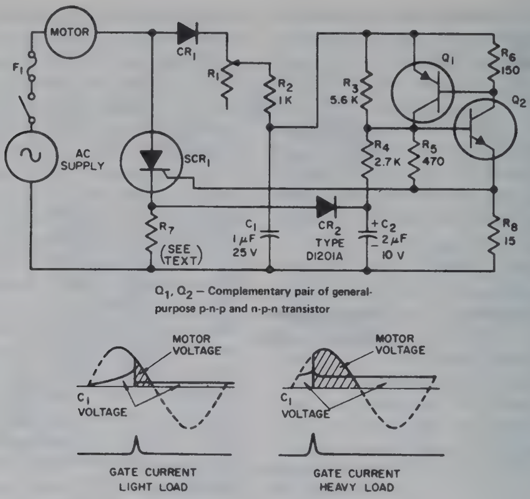
Fig.9 - Full-wave motor control with no regulation in which the conduction angle can be varied from 5 to 180 degrees.

The current ratings for the circuits using the 2N3528 and 2N3529 SCR's are based upon measurements made with these devices mounted by their electrical leads with the package in free air. The current ratings for the circuits using the other SCR types are based upon measurements made with the SCR's mounted on an aluminum heat sink having an equivalent dimension of 3 by 3 by 1/16 inches.

The SCR can be mounted on a single-plate heat sink or on a metal chassis. In chassis mounting the package housing and heat sink can be insulated from the chassis by a mica washer, as shown in Fig.11. The use of silicone grease or other similar material between the SCR housing and the heat sink provides a better thermal contact and more efficient heat dissipation. If heat dissipation is critical, a finned heat sink should

TABLE VI - COMPONENTS FOR CIRCUIT SHOWN IN FIG.9.

AC SUPPLY	AC CURRENT	F_1	R_2	SCR_1, SCR_2
120 V	1.5 A	3 AG, 2 A, Quick Act	75 K, 1/2 W	RCA-2N3528
120 V	5 A	3 AB, 5 A	75 K, 1/2 W	RCA-2N3228
120 V	10 A	3 AB, 10 A	75 K, 1/2 W	RCA-2N3669
240 V	1.5 A	3 AG, 2 A, Quick Act	150 K, 1/2 W	RCA-2N3529
240 V	5 A	3 AB, 5 A	150 K, 1/2 W	RCA-2N3525
240 V	10 A	3 AB, 10 A	150 K, 1/2 W	RCA-2N3670



Q_1, Q_2 – Complementary pair of general-purpose p-n-p and n-p-n transistor

Fig.10 - Full-wave motor control with regulation.

TABLE VII - COMPONENTS FOR CIRCUIT SHOWN IN FIG. 10.

AC SUPPLY	AC CURRENT	F_1	CR_1, CR_2, CR_3, CR_4	R_1	SCR_1
120 V	1 A	3 AG, 1.5 A, Quick Act	RCA-1N2860	50 K, 1/2 W	RCA-2N3528
120 V	3 A	3 AB, 3 A	RCA-1N1202A	50 K, 1/2 W	RCA-2N3228
120 V	7 A	3 AB, 7 A	RCA-1N1202A	50 K, 1/2 W	RCA-2N3669
240 V	1 A	3 AG, 1.5 A, Quick Act	RCA-1N2862	100 K, 1/2 W	RCA-2N3529
240 V	3 A	3 AB, 3 A	RCA-1N1204A	100 K, 1/2 W	RCA-2N3525
240 V	7 A	3 AB, 7 A	RCA-1N1204A	100 K, 1/2 W	RCA-2N3670

be used. Heat-sink size may be reduced in any application if moving air can be provided at the SCR mounting site.

If a universal motor is operated at low speed under a heavy mechanical load, it may stall and cause heavy current flow through the SCR. For this reason, low-speed heavy-load conditions should be allowed to exist for only a few seconds to prevent possible circuit damage. In any case, fuse ratings should be carefully observed and limited to the types and values indicated in the tables accompanying the circuits in this Note.

Practical heat sinks, packaging, available fuse characteristics, and motor overload and stall performance have been considered and are reflected in the current ratings shown for the circuits in this Note; these current values should not be exceeded.

Nameplate data for some universal motors are given in developed horsepower to the load. This mechanical designation can be converted into its electrical current equivalent through the following procedure.

Internal motor losses are taken into consideration by assigning a figure of merit. This figure, 0.5, represents motor operation at 50-per-cent efficiency, and indicates that the power input to the motor is twice the power delivered to the load. With this figure of merit and the input voltage V_{ac}, the rms input current to the motor can be calculated as follows:

$$\text{rms current} = \frac{\text{mechanical horsepower x 746}}{0.5\ V_{ac}}$$

For an input voltage of 120 volts, the rms input current becomes:

$$\text{rms current} = \text{horsepower x 12.4}$$

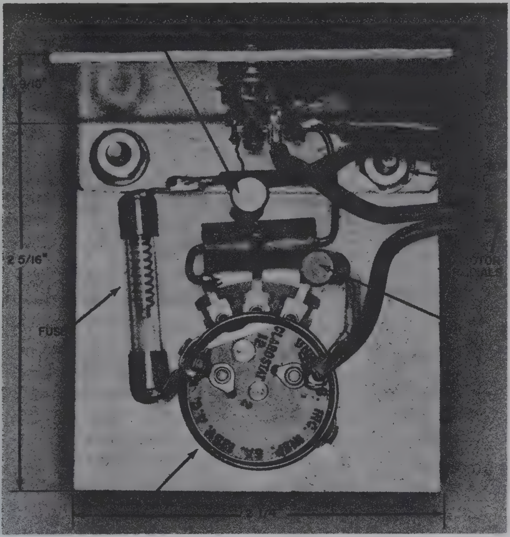


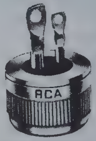
Fig.11 - Photograph of half-wave motor speed control.

or an input voltage of 240 volts, the rms input current ecomes:

rms current = horsepower x 6.2

The circuits in this Note should not be used with universal motors that have calculated rms current exceeding the values given in the tables. The circuits will accommodate universal motors with ratings up to 3/4 horsepower at 120 volts input and up to 1-1/2 horsepower at 240 volts input.

RCA SILICON CONTROLLED RECTIFIERS

RCA TYPE NO.	CURRENT - A		CASE TEMP. - °C	VOLTAGE - V	JEDEC PACKAGE
	ave.	rms			
2N3668	8	12.5	80	100	 TO-3
2N3669	8	12.5	80	200	
2N3670	8	12.5	80	400	
2N4103	8	12.5	80	600	
2N3528	1.3	2.0	25*	200	 TO-8
2N3529	1.3	2.0	25*	400	
2N4102	1.3	2.0	25*	600	
2N3228	3.2	5.0	75	200	 TO-66
2N3525	3.2	5.0	75	400	
2N4101	3.2	5.0	75	600	
2N681 - 2N690	16	25	65	25 - 600	 TO-48
2N1842A - 2N1850A	10	16	80	25 - 500	
2N3870	22	35	65	100	 Press Fit
2N3871	22	35	65	200	
2N3872	22	35	65	400	
2N3873	22	35	65	600	
2N3896	22	35	65	100	 Stud Mounted
2N3897	22	35	65	200	
2N3898	22	35	65	400	
2N3899	22	35	65	600	

*Ambient temperature.

Circuit Factor Charts for RCA Thyristor Applications (SCR's and Triacs)

by

B. J. Roman and J. M. Neilson

In the design of circuits using thyristors (SCR's and triacs), it is often necessary to determine the specific values of peak, average, and rms current flowing through the device. Although these values are readily determined for conventional rectifiers, the calculations are more difficult for thyristors because the current ratios become functions of both the conduction angle and the firing angle of the device.

This Note presents charts that show several current ratios as functions of conduction and firing angles for some of the basic SCR and triac circuits. Examples are given of the use of these charts in the design of half-wave, full-wave ac, full-wave dc, and three-phase half-wave circuits using RCA thyristors. Current and voltage waveforms for the various circuits are also included, as well as curves of per-cent ripple in load current and voltage.

Current-Ratio Curves

Figs. 1, 2, and 3 show current-ratio curves for a single-phase half-wave SCR circuit with resistive load, a single-phase SCR or triac full-wave circuit with resistive load, and a three-phase half-wave SCR circuit with resistive load, respectively. These curves relate average current I_{avg}, rms current I_{rms}, and peak current I_{pk} to a reference current I_o. This reference current I_o is a constant of the circuit equal to the peak source voltage V_{pk} divided by the load resistance R_L; it represents the maximum value that the current can obtain and corresponds to the peak of the sine wave. The peak current I_{pk} is the current which appears at the thyristor during its period of forward conduction. For conduction angles greater than 90 degrees, I_{pk} is equal to I_o; for conduction angles smaller than 90 degrees, I_{pk} is smaller than I_o.

The curves of Figs. 1, 2, and 3 can be used in a number of ways to calculate desired current values. For example, they can be used to determine the peak or rms current in a thyristor when a specified average current is to be delivered to a load during a given part of the conduction period. It is also possible to work backwards and determine the necessary period of conduction to maintain a specified peak-to-average current ratio in a particular application. Another use is the calculation of rms current at various conduction angles when it is necessary to determine the power delivered to a load, or power losses in transformers, motors, leads, or bus bars. Although the curves represent device currents, they are equally useful for calculation of load current and voltage ratios.

For use of these curves, it is first necessary to identify the unknown or desired parameter. The values of the parameters fixed by the circuit specifications are then determined, and the appropriate curve is used to obtain the unknown quantity as a function of two of the fixed parameters. Examples of the use of the curves are given to illustrate their versatility.

Half-Wave SCR Circuit

In the single-phase half-wave circuit shown in Fig. 4, an SCR is used to control power from a sinusoidal ac source of 120 volts rms (170 volts peak) into a 2.8-ohm load. This application requires a load current which can be varied from 2 to 25 amperes. It is necessary to determine the range of conduction angles required to obtain this range of load current.

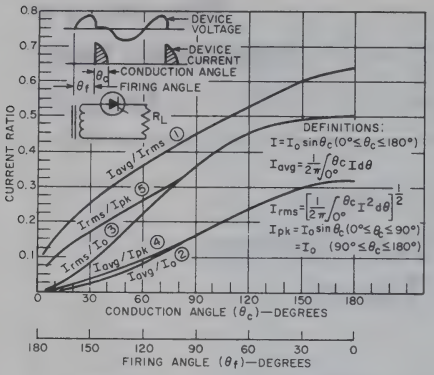


Fig. 1 - SCR current ratios for single-phase, half-wave conduction with resistive load.

The reference current I_o is first calculated, as follows:

$$I_o = \frac{V_{pk}}{R_L} = \frac{170}{2.8} = 61 \text{ amperes}$$

The ratio of rms current I_{rms} to I_o is then calculated for the maximum and minimum load-current requirements, as follows:

$$(I_{rms}/I_o)_{max} = (25/61) = 0.41$$

$$(I_{rms}/I_o)_{min} = (2/61) = 0.033$$

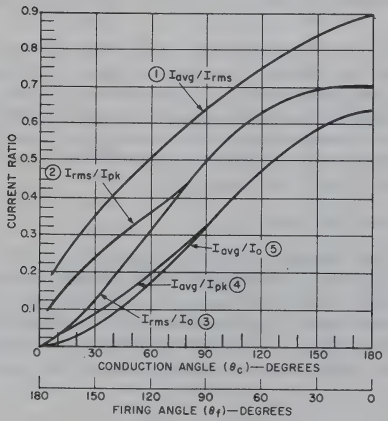


Fig. 2 - SCR or triac current ratios for single-phase, full-wave conduction with resistive load.

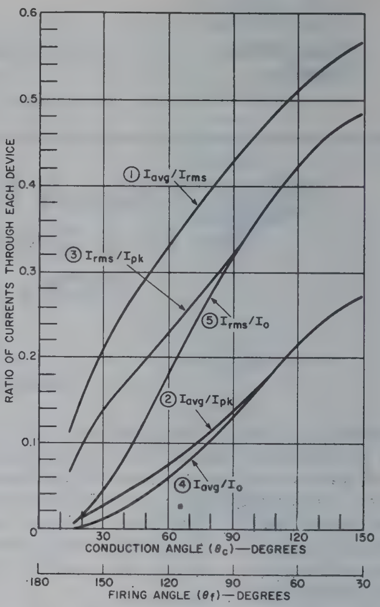


Fig. 3 - SCR current ratios for three-phase half-wave circuit with resistive load.

The conduction angles corresponding to the ratios can then be determined by use of curve 3 in Fig. 1:

$$\theta_c \max = 106°$$

$$\theta_c \min = 15°$$

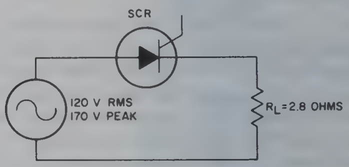


Fig. 4 - Half-wave SCR circuit.

Full-Wave AC Triac Circuit

Fig. 5 shows a circuit in which a triac is used to control the power to a 20-ohm resistive load. It is desired to find the range of conduction angles the gate circuit must be capable of supplying to provide continuous variation in load power between 5 and 97 percent of the full power which the load could draw.

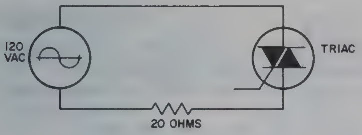

120 VAC
TRIAC
20 OHMS

Fig. 5 - Full-wave triac control circuit.

Full power P is given by

$$P = \frac{V_{rms}^2}{R_L} = \frac{120^2}{20} = 720 \text{ watts}$$

Therefore, the 5- and 97-per-cent power points are as follows:

$$P_5 = 36 \text{ watts}$$

$$P_{97} = 698 \text{ watts}$$

The rms current corresponding to each point is given by

$$I_5 = \sqrt{P_5/R_L} = \sqrt{36/20} = 1.3 \text{ amperes rms}$$

$$I_{97} = \sqrt{P_{97}/R_L} = \sqrt{698/20} = 5.9 \text{ amperes rms}$$

The reference current I_o is determined as follows:

$$I_o = \frac{V_{peak}}{R_L} = \frac{120 \times \sqrt{2}}{20} = 8.5 \text{ amperes}$$

The current ratios for the 5- and 97-per-cent power levels then become

at 5%, I_{rms}/I_o = 1.3/8.5 (amperes) = 0.153

at 97%, I_{rms}/I_o = 5.9/8.5 (amperes) = 0.695

Because the circuit shown in Fig. 5 is a full-wave circuit, the calculated current ratios are used in curve 3 of Fig. 2 to determine the required conduction angles:

at 5% power, conduction angle = 35°

at 97% power, conduction angle = 150°

Thus, the load power is continuously variable from 5 to 97 per cent of full load if the gate circuit is constructed so that the conduction angle can be varied between 35 and 150 degrees. This variation is within the range which can be obtained with a simple trigger-diode type of gate circuit.

Full-Wave DC SCR or Triac Circuit

Fig. 6 shows several different SCR circuits and a triac circuit which can be used to supply a constant dc output to a variable load resistance with an ac input of 64 volts rms. It is desired to determine the variation in conduction angle required to maintain the average load current at a constant value of 30 amperes while the load resistance varies between 0.12 and 1.80 ohms.

The reference currents are calculated for maximum and minimum values of load resistance, as follows:

$$I_{o_{max}} = \frac{V_{peak}}{R_{L_{min}}} = \frac{64\sqrt{2}}{0.12} = 750 \text{ amperes}$$

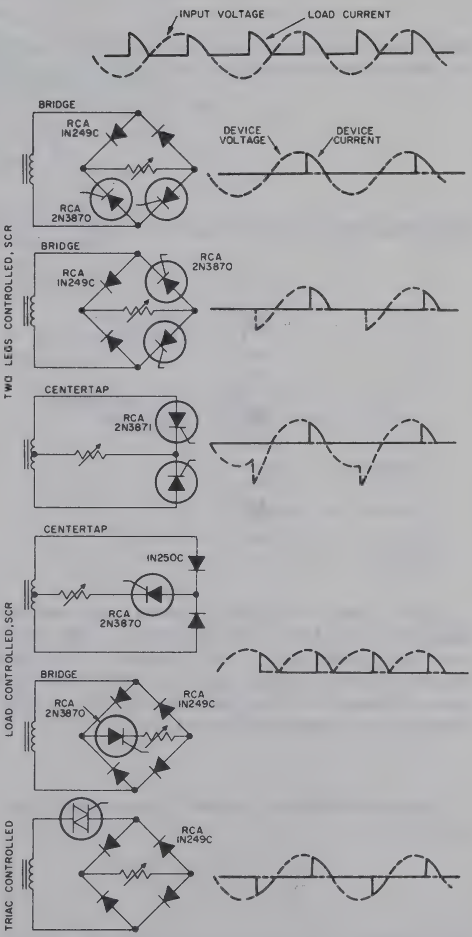

INPUT VOLTAGE
LOAD CURRENT
BRIDGE
RCA IN249C
RCA 2N3870
DEVICE VOLTAGE
DEVICE CURRENT
BRIDGE
RCA IN249C
RCA 2N3870
CENTERTAP
RCA 2N3871
TWO LEGS CONTROLLED, SCR
CENTERTAP
IN250C
RCA 2N3870
BRIDGE
RCA 2N3870
RCA IN249C
LOAD CONTROLLED, SCR
RCA IN249C
TRIAC CONTROLLED

Fig. 6 - Typical current and voltage waveforms for single-phase, full-wave thyristor circuits with resistive load.

$$I_{o_{min}} = \frac{V_{peak}}{R_{L_{max}}} = \frac{64\sqrt{2}}{1.80} = 50 \text{ amperes}$$

The ratios of I_{avg} to I_o for an average load current of 30 amperes are then calculated as follows:

$$\frac{I_{avg}}{I_{o_{max}}} = \frac{30}{750} = 0.04$$

$$\frac{I_{avg}}{I_{o_{min}}} = \frac{30}{50} = 0.60$$

The conduction angles corresponding to these two ratios can then be obtained from curve 5 in Fig. 2:

$$\theta_{c_{min}} = 28^\circ$$

$$\theta_{c_{max}} = 153^\circ$$

Three-Phase Half-Wave SCR Circuit

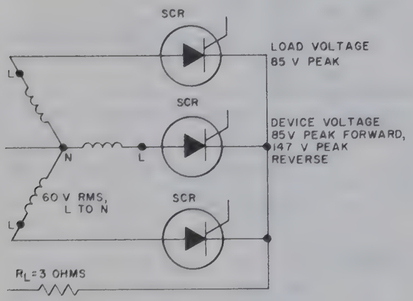

SCR
LOAD VOLTAGE 85 V PEAK
L
SCR
DEVICE VOLTAGE 85V PEAK FORWARD, 147 V PEAK REVERSE
N
L
60 V RMS, L TO N
SCR
L
R_L=3 OHMS

Fig. 7 shows a three-phase, half-wave circuit that uses three SCR's. In this application, the firing angle can be varied continuously from 30 to 145 degrees. It is desired to determine the resulting variation in the attainable load power. Current and voltage waveforms for SCR's in three-phase, half-wave circuits are shown in Fig. 8.

Again, the reference current I_o is calculated first, as follows:

$$I_o = \frac{V_L peak}{R_L} = \frac{85}{3} = 28 \text{ amperes}$$

Current ratios at the extremes of the firing range are determined from Fig. 3. For the specified firing angles, the current ratios are given by

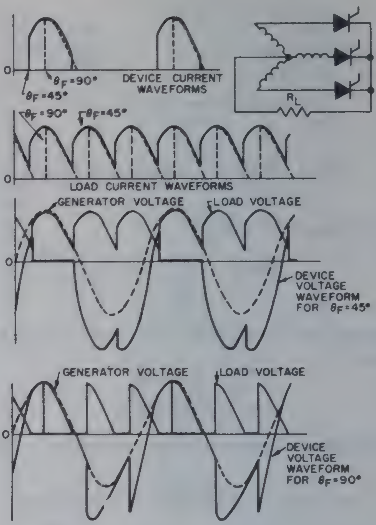

0
θ_F=90°
θ_F=45°
DEVICE CURRENT WAVEFORMS
R_L
θ_F=90°
θ_F=45°
0
LOAD CURRENT WAVEFORMS
GENERATOR VOLTAGE
LOAD VOLTAGE
0
DEVICE VOLTAGE WAVEFORM FOR θ_F=45°
GENERATOR VOLTAGE
LOAD VOLTAGE
0
DEVICE VOLTAGE WAVEFORM FOR θ_F=90°

Fig. 8 - Typical current and voltage waveforms for three-phase, half-wave SCR circuit with resistive load.

$$\frac{I_{rms}}{I_o} = 0.49 \text{ for } \theta_f = 30^\circ$$

$$\frac{I_{rms}}{I_o} = 0.06 \text{ for } \theta_f = 145^\circ$$

These ratios, together with the reference current, ar then used to determine the range of rms current in th SCR's, as follows:

$$I_{rms} \max = (0.49)(28) = 13.7 \text{ amperes}$$

$$I_{rms} \min = (0.06)(28) = 1.7 \text{ amperes}$$

In this type of circuit, the rms load current is equa to the rms SCR current multiplied by the square root o three. The load power P, therefore, is given by

$$P = (I_{rms}\sqrt{3})^2 \ (R)$$

The range of load power can then be determined a follows:

$$P_{max} = 1700 \text{ watts}$$

$$P_{min} = 27 \text{ watts}$$

In other words, the load power can be varied continuousl from 27 to 1700 watts.

Per-Cent Ripple in Load

The choice of a rectifier circuit for a particular pplication often depends on the amount of rectifier ripple" (undesired fluctuation in the dc output caused by an ac component) that can be tolerated in the application. Fig. 9 shows per-cent ripple in load current and voltage for single-phase half-wave, single-phase full-wave, and three-phase half-wave thyristor circuits.

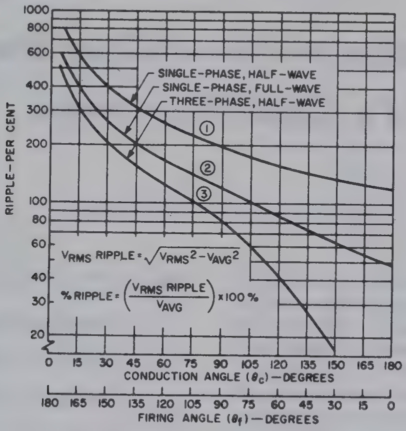


Fig. 9 - Output ripple in thyristor circuits as a function of conduction and firing angles.

Solid State
Division

Thyristors
Application Note
AN-3659

Application of RCA Silicon Rectifiers To Capacitive Loads

by

B. J. Roman and J. M. S. Neilson

When rectifiers are used in capacitive-load circuits, the rectifier current waveforms may deviate considerably from their true sinusoidal shape. This deviation is most evident for the peak-to-average current ratio, which is somewhat higher than that for a resistive load. Because of the variation in current waveshapes, calculations of ratings for capacitive-load circuits are generally more complicated and time-consuming than those for resistive-load rectifier circuits.

This Note describes a simplified rating system which allows designers to calculate the characteristics of capacitive-load rectifier circuits quickly and accurately. The effect of the addition of a series limiting resistance to such circuits and the importance of the ratio of the limiting resistance to capacitive reactance are described, and curves of rectifier current ratios are presented as functions of the effective ratio. Typical design examples are given, and output-ripple considerations are discussed. Table I defines the symbols used in the equations and calculations.

Design of Capacitor-Input Circuits

In the design of a rectifier circuit, the output voltage and current, the input voltage, and the ripple and regulation requirements are usually specified. The transformer and the type of rectifier to be used are selected by the designer, and the load resistance is determined on the basis of the output voltage and current requirements. The ripple requirements are satisfied by use of a capacitor to shunt the load R_L, as shown in Fig. 1. The waveforms for this circuit indicate that the voltage across the capacitor E_C coincides with the supply voltage E when the rectifier is conducting in the forward direction. A high initial diode surge current I_S occurs because the capacitor acts as a short circuit when power is first applied. The diode turns off at the peak of the curve (point0), and remains off until E_C is again equal to E (point A). The turn on point t_{on} is determined by the time constant R_LC, and affects the average, peak, and rms currents through the device.

As stated above, the low forward voltage drop of silicon rectifiers may result in a very high surge of current when the capacitive load is first energized. Although the generator or source impedance may be high

Table I – Definition of Symbols

E = sinsusoidal input voltage ($E = E_o \sin \omega t$)

E_o = peak input voltage

E_{avg} = average output voltage

f = input frequency (Hz)

ω = angular frequency of input ($\omega = 2\pi f$ radians per second)

t = time counted from beginning of cycle

R_S = limiting resistance

R_L = load resistance

C = load capacitance

I_o = absolute peak current through rectifier

I_{pk} = actual peak current through rectifier

Irms = root-mean-squafe current through rectifier

I_{avg} = average current through rectifier

n = charge factor; 1 for half-wave circuit, ½ for doubler circuit, 2 for full-wave circuit

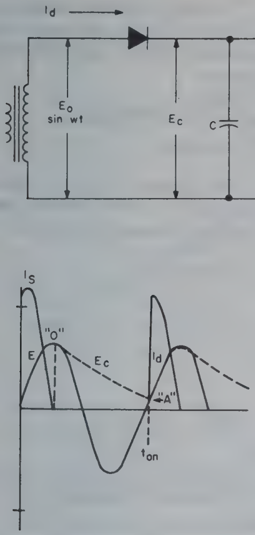


Fig.1 - Circuit showing use of capacitor to shunt the load, and resulting waveforms.

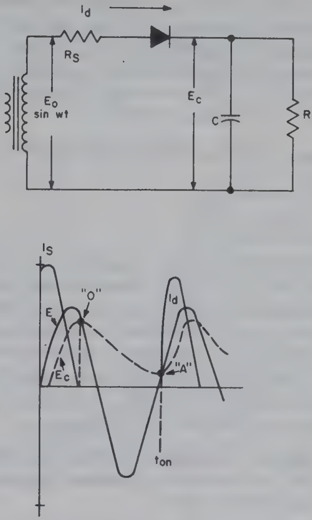


Fig.2 - Circuit showing addition of limiting resistance, and resulting waveforms.

enough to protect the rectifier, in some cases additional resistance must be added to the generator-rectifier-capacitor loop, as shown in Fig.2, to keep the surge vithin device ratings. The waveforms in Fig.2 show hat the capacitor voltage E_C is no longer coincident vith the steady state supply voltage E during any part of the cycle. The sum of the additional limiting resis-ance plus the source resistance is referred to as the otal limiting resistance R_S. The ratio of R_S to capacitive reactance $1/\omega C$ is an important consideration n capacitor-input rectifier circuits; ideally, R_S should e much smaller than $1/\omega C$. The magnitude of R_S re-uired in a particular circuit is calculated as described elow.

Calculation of Limiting Resistance

The value of resistance required to protect the rectifier is calculated from the surge rating chart for the particular device used. Fig. 3 shows surge rating charts for diffused junction stack rectifiers CR1 and CR2. Each point on the curves defines a surge rating by indicating the maximum time for which the device can safely carry a specific value of rms current.

With a capacitive load, maximum surge current occurs if the circuit is switched on when the input voltage s near its peak value. When the time constant R_SC of he surge loop is much smaller than the period of the

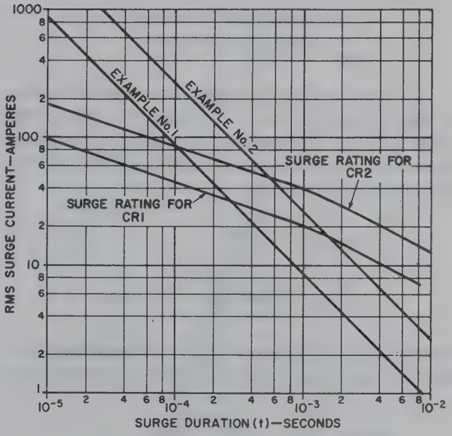


Fig.3 - Surge-rating chart used for calculation of limiting resistance.

input voltage, the peak current is equal to the peak input voltage E_o divided by the limiting resistance R_S, and the resulting surge I_S approximates an exponentially decaying current with the time constant R_SC,as follows:

$$I_S = (E_o/R_S)\ \exp\ (-1/R_SC) \qquad (1)$$

Surge-current ratings for rectifiers are often given in terms of the rms value of the surge current and the time duration t of the surge, as shown in Fig. 3. For rating purposes, the surge duration t is defined as the time constant R_SC. The rms surge current is then approximated by the following equations:

$$I_{rms} = 0.7\,(E_oC/R_SC) = 0.7\,(E_oC/t) \qquad (2)$$

and

$$I_{rms}\,t = 0.7\,E_oC \qquad (3)$$

The values for E_o and C specified by the circuit design are used in Eq.(3) to obtain an equation which relates the rms surge current I_{rms} to surge duration t. This equation may then be plotted on the surge rating chart. Because R_SC is equal to t, any given value of R_S defines a specific time t, and hence a specific point on the plot of Eq.(3). However, R_S must be large enough to make this point fall below the rating curve.

The following examples illustrate the procedure described for calculating the limiting resistance required in a particular circuit.

Example No. 1: Fig. 4 shows a half-wave rectifier circuit that has a 60-Hz frequency and a peak input voltage E_o of 4950 volts. The values of E_o and C are substituted in Eq.(3) to obtain the value of $I_{rms}t$, as follows:

$$I_{rms}t = 0.7\,(4950)\,(2.5 \times 10^{-6})$$

$$I_{rms}\,t = 0.0086$$

This value is then plotted on the surge-rating chart of Fig. 3 and is found to intersect the CR1 rating curve at 2.7 x 10^{-4} second. The minimum limiting resistance which affords adequate surge protection is then calculated as follows:

$$R_SC \geq 2.7 \times 10^{-4}$$

$$R_S \geq \frac{2.7 \times 10^{-4}}{2.5 \times 10^{-6}} = 108 \text{ ohms}$$

Because the value given for R_S is 150 ohms, the circuit has adequate surge-current protection for the rectifiers.

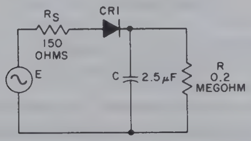


Fig.4 - Half-wave rectifier circuit (E = 3500 V rms, E_o = 3820 V, f = 60 Hz).

Example No. 2: The doubler circuit shown in Fig. 5 has a peak input voltage of 3800 volts and a load capacitance of 10 microfarads. These values are substituted into Eq. (3), as follows:

$$I_{rms}t = (0.7)\ (3800)\ (10^{-5})$$

$$I_{rms}\,t = 0.0266$$

This value is then plotted on Fig.3 and intersects the CR2 rating curve at 5.4 x 10^{-4} second. Therefore, the equation for the time constant is given by

$$R_SC \geq 5.4 \times 10^{-4}$$

$$R_S \geq \frac{5.4 \times 10^{-4}}{10^{-5}} = 54 \text{ ohms}$$

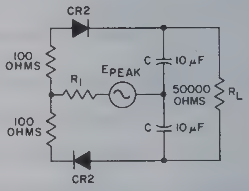


Fig.5 - Voltage-doubler rectifier circuit (E = 2700 V rms, E_o = 3820 V, f = 60 Hz).

Calculation of Rectifier Current

The design of rectifier circuits using capacitive loads often requires the determination of rectifier current waveforms in terms of average, rms, and peak currents. These waveforms are needed for calculations of circuit parameters, selection of components, and matching of circuit parameters with rectifier ratings. Actual calculation of rectifier current is a rather lengthy process. A much more direct process is to use the current-relationship charts shown in Figs. 6 and 7. These curves can be readily used to find peak or rms current if the average current is known, or vice versa.

The ratios of peak-to-average current and rms-to-average current are shown in Fig. 6 as functions of the circuit constants $n\omega CR_L$ and R_S/nR_L. The quantity ωCR_L is the ratio of resistive-to-capacitive reactance in the load, and the quantity R_S/R_L is the ratio of limiting resistance to load resistance. The factor n is referred to as the "charge factor" and is simply a multiplier which allows the chart to be used for various circuit configurations. It is equal to unity for half-wave circuits, ½ for doubler circuits, and 2 for full-wave circuits. (These values actually represent the relative quantity of charge delivered to the capacitor on each cycle).

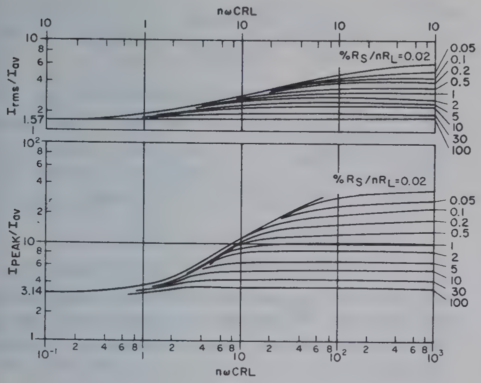


Fig.6 - Relation of peak, average, and rms rectifier currents in capacitor-input circuits.

In many silicon rectifier circuits, R_S may be completely neglected when compared with the magnitude of R_L. In such circuits, the calculation of rectifier current is even more simplified by the use of Fig. 7, which gives current ratios under the limitation that R_S/R_L approaches zero. Even if this condition is not fully satisfied, the use of Fig. 7 merely indicates a higher peak and higher rms current than will actually flow in the circuit; as a result, the rectifiers will operate more conservatively than calculated. This simplified solution can be used whenever a rough approximation or a quick check is needed on whether a rectifier will fit the application. When more exact information is needed, Fig.6 should be used.

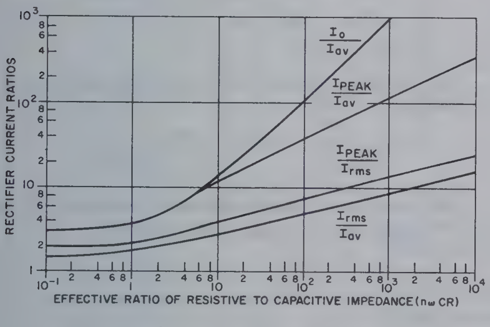


Fig.7 - Forward-current ratios for rectifiers in capacitor-input circuits in which the limiting resistance is much less than 1/ ωC.

Average output voltage E_{avg} is another important quantity because it can be used to find average output current. The relations between input and output voltages for half-wave, voltage-doubler, and full-wave circuits are given in Figs. 8,9, and 10, respectively. Output ripple is shown in Fig. 11 for all three circuits. Although these curves were originally calculated for vacuum-tube rectifiers, they are equally applicable to silicon rectifier circuits.

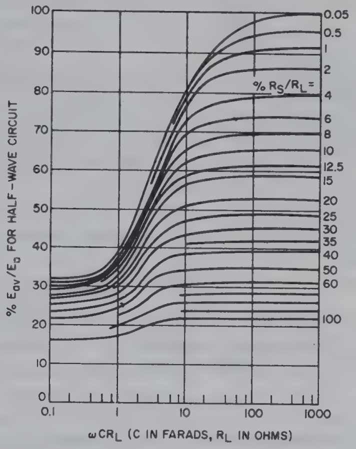


Fig.8 - Relation of applied alternating peak voltage to direct output voltage in half-wave capacitor-input circuits.

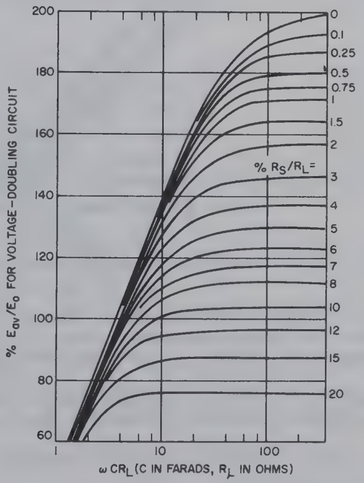


Fig.9 - Relation of applied alternating peak voltage to direct output voltage in capacitor-input voltage doubler circuits.

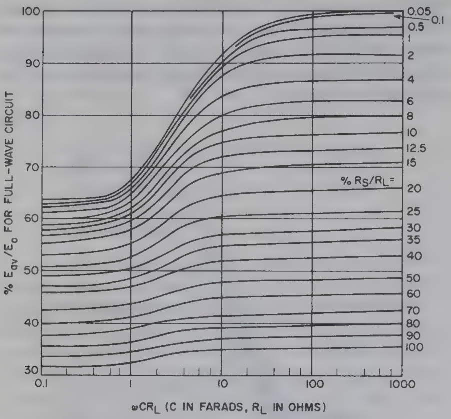


Fig. 10 - Relation of applied alternating peak voltage to direct output voltage in full-wave capacitor-input circuits.

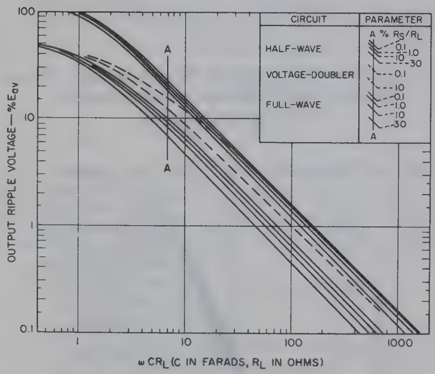


Fig. 11 - RMS ripple voltage of capacitor-input circuits.

The following examples illustrate the use of Figs. 8 through 11 in rectifier-current calculations. Both exact and approximate solutions are given for each example.

Example No. 3: For the half-wave circuit of Fig. 4, the resistive-to-capacitive reactance is found to be:

$$\omega CR_L = (2\pi)(60)\ (2.5 \times 10^{-6})\ (200{,}000)$$

$$\omega CR_L = 189$$

Exact solution using Fig. 6: The ratio of R_S to R_L must first be calculated as follows:

$$\% \frac{R_S}{R_L} = \frac{150 \times 100\%}{200{,}000} = 0.075\%$$

The values given above are then plotted in Fig. 8 to determine average output voltage and average output current, as follows:

$$E_{avg}/E_o = 98\%$$

$$E_{avg} = (0.98)\ (4950) = 4850 \text{ volts}$$

$$I_{avg} = E_{avg}/R_L$$

$$I_{avg} = 4850/200{,}000 = 24.2 \text{ milliamperes}$$

This value of I_{avg} is then substituted in the ratio of I_{rms}/I_{avg} obtained from Fig. 6, and the exact value of rms current in the rectifier is determined, as follows:

$$I_{rms}/I_{avg} = 4.4$$

$$I_{rms} = (4.4)\ (24.2) = 107 \text{ milliamperes}$$

Simplified solution using Fig. 7: Average output current is approximately equal to peak input voltage divided by load resistance, as given by

$$I_{avg} = E_o/R_L$$

$$I_{avg} = 4950/200{,}000 = 24.7 \text{ milliamperes}$$

This value of I_{avg} is then substituted in the ratio of I_{rms}/I_{avg} obtained from Fig. 7 and the approximate rms current is determined, as follows:

$$I_{rms}/I_{avg} = 5.7$$

$$I_{rms} = (5.7)\ (24.7) = 141 \text{ milliamperes}$$

Example No. 4: For the doubler circuit of Fig. 5, the resistive-to-capacitive reactance is determined as follows:

$$\omega CR_L = (2\pi)\ (60)\ (10^{-5})\ (50{,}000)$$

$$\omega CR_L = 189$$

$$n\,\omega CR_L = 94$$

Exact solution: The ratio of R_S to R_L is determined as follows:

$$\% \frac{R_S}{R_L} = \frac{100 \times 100\%}{50{,}000} = 0.2\%$$

This percentage is then used in conjunction with Fig. 9, and E_{avg} and I_{avg} are determined as follows:

$$E_{avg}/E_o = 186\%$$

$$E_{avg} = (1.86)\ (3820) = 7100 \text{ volts}$$

$$I_{avg} = E_{avg}/R_L$$

$$I_{avg} = 7100/50{,}000 = 142 \text{ milliamperes}$$

The values given above are then plotted in Fig. 6, and the rms current is calculated as follows:

$$I_{rms}/I_{avg} = 3.7$$

$$I_{rms} = (3.7)\ (142) = 525 \text{ milliamperes}$$

Simplified solution: The average output current is given by

$$I_{avg} = 2E_o/R_L$$

$$I_{avg} = (2 \times 3820)/50{,}000 = 153 \text{ milliamperes}$$

This value is then plotted in Fig. 7, and the rms cur- is determined as follows:

$$I_{rms}/I_{avg} = 4.8$$

$$I_{rms} = (4.8)\ (153) = 734 \text{ milliamperes}$$

As previously noted, the simplified solution in both examples predicted a higher rms current than the actual value: about 32 per cent higher in Example No. 3 and 40 per cent higher in Example No. 4. The amount of error involved depends on both ωCR_L and R_S/R_L.

Rating Curves for RMS Current Versus Temperature

In most technical data for rectifiers, the current-versus-temperature ratings are given in terms of average current for a resistive load with 60-Hz sinusoidal input voltage. However, when the ratio of peak-to-average current becomes higher (as with capacitive loads), junction heating effects become more and more dependent on rms current rather than average current. Therefore, the capacitive-load ratings should be obtained from a curve of rms current as a function of temperature. The average current-rating curves for a sinusoidal source and resistive load may be converted to rms-rating curves simply by multiplying the current axis by 1.57 because this value is the ratio of rms-to-average current for such service (as shown by I_{rms}/I_{avg} at low ωCR_L in Figs. 6 and 7). An example of this conversion is shown in Fig. 12 for the rating curves of seven stack rectifiers.

The following examples illustrate the use of the rms current ratings.

Example No. 5: For the half-wave circuit of Fig. 4, it was found in Example No. 3 that the actual rms current in the rectifier is 107 milliamperes. The rms rating curve in Fig. 12 shows that the CR7 may carry up to 107 milliamperes at ambient temperatures up to 115°C.

Example No. 6: For the doubler circuit of Fig. 5, the actual rms current was determined to be 525 milliamperes. The rms rating curve for the CR6 in Fig. 12 shows that the circuit may be operated up to 88° C ambient temperature.

Example No. 7: If the higher values of rms current given by the simplified solution are used instead of the actual currents, the rms rating curves of Fig. 12 also give more conservative ratings because they predict a lower value for the maximum permissible ambient temperature. For example, for the half-wave circuit the exact rms current was found to be 107 milliamperes, and the approximate value was 141 milliamperes. These current values correspond to a maximum ambient temperature rating of 115°C by the exact solution and 110°C by the approximate solution.

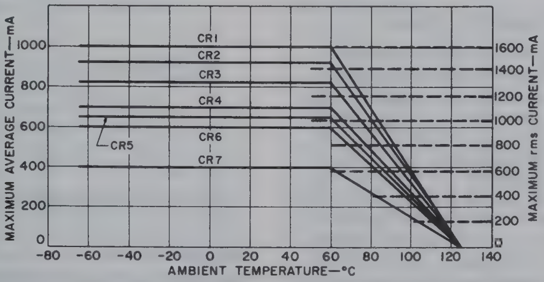


Fig. 12 - Current as a function of temperature for silicon rectifier stacks.

RCA
Solid State Division

Thyristors
Application Note
AN-3697

TRIAC POWER-CONTROL APPLICATIONS

by

J. V. YONUSHKA

In the control of ac power by means of semiconductor devices, emphasis has been placed upon limiting the complexity of the circuits involved, the cost of the system, and the over-all package size. With the development of the bidirectional triode thyristor, commonly known as the triac, all of these goals can be achieved. A triac can perform the functions of two SCR's for full-wave operation and can easily be triggered in either direction to simplify gate circuits. Because they are rated for 120-volt and 240-volt line operation, triacs are readily adaptable for the control of power to any equipment being operated directly from ac power lines. When used for ac power control, triacs add new functions to many designs, improve performance, and provide maximum efficiency and high reliability. This Note describes triac operating characteristics and provides guidance in the use of triacs for specific applications.

Principal Voltage-Current Characteristic Diagram

Fig. 1 shows the principal voltage-current characteristic of a triac. This curve shows the current through the triac as a function of the voltage applied between main terminals Nos. 1 and 2. In quadrant I, the voltage on main terminal No. 2 is positive with respect to main terminal No. 1; in quadrant III, the voltage on main terminal No. 2 is negative with respect to main terminal No. 1. When a positive voltage is applied to main terminal No. 2, as shown by the curve in quadrant I, a point is reached, called the breakover voltage V_{BO}, at which the device switches from a high-impedance state to a low-impedance state. The current can then be increased through the triac with only a small increase in voltage across the device. The triac remains in the ON state until the current through the main terminals drops below a value, called the holding current, which cannot maintain the breakover condition. The triac then reverts again to the high-impedance or OFF state. If the voltage across the main terminals of the triac is reversed, the same switching action occurs as shown by the curve in quadrant III. Thus, the triac is capable of switching from the OFF state to the ON state for either polarity of voltage applied to the main terminals.

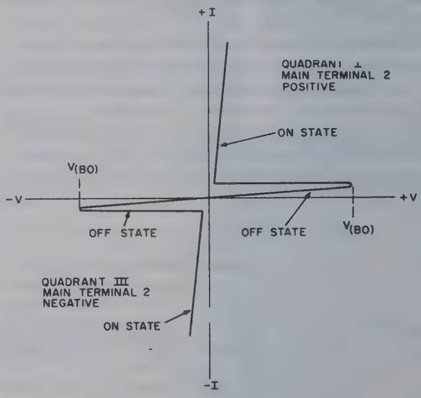
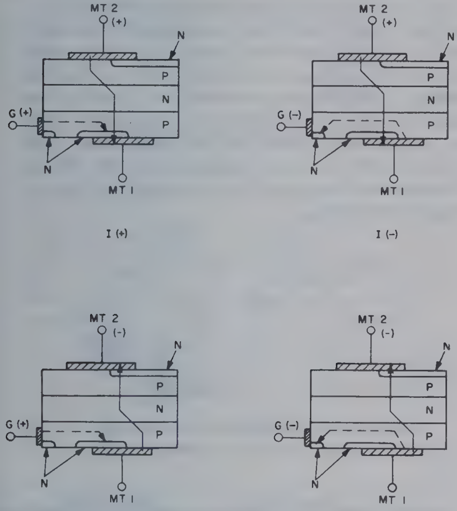


Fig. 1 — Triac principal voltage-current characteristics

Gate Characteristics

When a trigger current is applied to the gate terminal of a triac, the breakover voltage is reduced. After the triac is triggered, the current flow through the main terminals is independent of the gate signal and the triac remains in the ON state until the principal current is reduced below the holding-current level. The triac has the unique capability of being triggered by either a positive or a negative gate signal regardless of the voltage polarity across the main terminals of the device. Fig. 2 illustrates the triggering mechanism and current flow within a triac. The gate trigger polarity is always referenced to main terminal No. 1. The potential difference between the two terminals is such that gate current flows in the direction indicated by the dotted arrow. The polarity symbol at main terminal No. 2 is also referenced to main terminal No. 1. The semiconductor materials between the various junctions within the pellet are labeled p and n to indicate the type of majority-carrier concentrations within the material.



I (+)   I (–)

III (+)   III (–)

Fig. 2 – Current flow in a triac.

For the various operating modes, the polarity of the voltage on main terminal No. 2 with respect to main terminal No. 1 is given by the quadrant in which the triac operates, (either I or III) and the polarity of the gate signal used to trigger the device is given by the proper symbol next to the operating quadrant. For the I (+) operating mode, therefore, main terminal No. 2 and the gate are both positive with respect to main terminal No. 1. Initial gate current flows into the gate terminal, through the p-type layer, across the junction into the n-type layer, and out main terminal No. 1, as shown by the dotted arrow. As gate current flows, current multiplication occurs and the regenerative action within the pellet switches the triac to its ON state. Because of the polarities indicated between the main terminals, the principal current flows through the pnpn structure as shown by the solid arrow. Similarly, for the other three operating modes, the initial gate current flow is shown by the dotted arrow, and principal current flow through the main terminals is shown by the solid arrow.

Because the principal current influences the gate trigger current, the magnitude of the current required to trigger the triac differs for each mode. The operating modes in which the principal current is in the same direction as the gate current require less gate trigger current, while modes in which the principal current is in opposition to the gate current require more gate trigger current.

Like many other semiconductor parameters, the magnitude of the gate trigger current and voltage varies with the junction temperature. As the thermal excitation of carriers within the semiconductor increases, the increase in leakage current makes it easier for the device to be triggered by a gate signal. Therefore, the gate becomes more sensitive in all operating modes as the junction temperature increases. Conversely, if the triac is to be operated at low temperatures, sufficient gate trigger current must be provided to assure triggering of all devices at the lowest operating temperature expected in any particular application. Variations of gate trigger requirements are given in the data sheets for individual triacs.

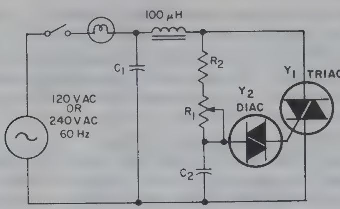
Light Control

Because the light output of an incandescent lamp depends upon the voltage impressed upon the lamp filament, changes in the lamp voltage vary the brightness of the lamp. When ac source voltages are used, a triac can be used in series with an incandescent lamp to vary the voltage to the lamp by changing its conduction angle; i.e., the portion of each half cycle of ac line voltage in which the triac conducts to provide voltage to the lamp filament. The triac, therefore, is very attractive as a switching element in light-dimming applications.

To switch incandescent-lamp loads reliably, a triac must be able to withstand the inrush current of the lamp load. The inrush current is a result of the difference between the cold and hot resistance of the tungsten filament. The cold resistance of the tungsten filament is much lower than the hot resistance. The resulting inrush current is approximately 12 times the normal operating current of the lamp.

The simplest circuit that can be used for light-dimming applications is shown in Fig. 3 and uses a trigger diode in series with the gate of a triac to minimize the variations in gate trigger characteristics. Changes in the resistance in series with the capacitor change the conduction angle of the triac.

The capacitor in the circuit of Fig. 3 is charged through the control potentiometer and the series resistance. The series resistance is used to protect the potentiometer potentiometer is at its minimum resistance setting. This resistor may be eliminated if the potentiometer can withstand the peak charging current until the triac turns on. The trigger diode conducts when the voltage on the capacitor reaches the diode breakover voltage. The capacitor then discharges through the trigger diode to produce a current pusle of sufficient amplitude and width to trigger the triac. Because the triac can be triggered with either



	120VAC, 60Hz	240VAC, 60Hz
R_1	200kΩ, ½W	250kΩ, 1W
R_2	3.3kΩ, ½W	4.7kΩ, ½W
C_1	0.1µF, 200V	0.1µF, 400V
C_2	0.1µF, 100V	0.1µF, 100V
Y_1	T2800B	T2800D
Y_2	D3202U	D3202U

Fig. 3 – Single-time-constant light-dimmer circuit.

polarity of gate signal, the same operation occurs on the opposite half-cycle of the applied voltage. The triac, therefore, is triggered and conducts on each half-cycle of the input supply voltage.

The interaction of the RC network and the trigger diode results in a hysteresis effect when the triac is initially triggered at small conduction angles. The hysteresis effect is characterized by a difference in the control potentiometer setting when the triac is first triggered and when the circuit turns off. Fig. 4 shows the interaction between the RC network and the trigger diode to produce the hysteresis effect. The capacitor voltage and the ac line voltage are shown as solid lines. As the resistance in the circuit is decreased from its maximum value, the capacitor voltage reaches a value which fires the trigger diode. This point is designated A on the capacitor-voltage wave-shape. When the trigger diode fires, the capacitor discharges and triggers the triac at an initial conduction angle θ_1. During the forming of the gate trigger pulse, the capacitor voltage drops suddenly. The charge on the capacitor is smaller than when the trigger diode did not conduct. As a result of the different voltage conditions on the capacitor, the breakover voltage of the trigger diode is reached earlier in the next half-cycle. This point is labeled point B on the capacitor-voltage waveform. The conduction angle θ_2 corresponding to point B is greater than θ_1. All succeeding conduction angles are equal to θ_2 in magnitude. When the circuit resistance is increased by a change in the potentiometer setting the triac is still triggered, but at a smaller conduction angle. Eventually, the resistance in series with the capacitance becomes so great that the voltage on the capacitor does not reach the breakover voltage of the trigger diode. The circuit then turns off and does not turn on until the circuit resistance is again reduced to allow the trigger diode to be fired. The hysteresis effect makes the voltage load appear much greater than would normally be expected when the circuit is initially turned on.

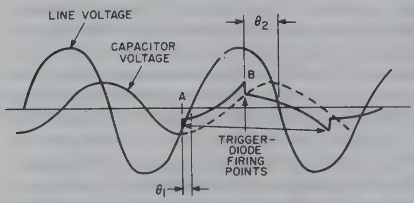
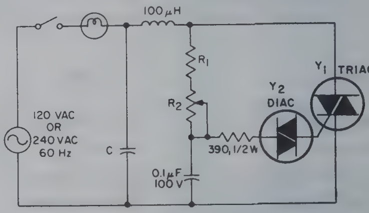


Fig. 4 – Waveforms showing interaction of control network and trigger diode.

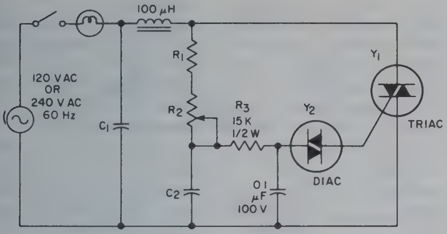
The hysteresis effect can be reduced by use of a resistor in series with the trigger diode and gate, as shown in Fig. 5. The series resistor slows down the discharge of the capacitor through the trigger diode. Consequently, the capacitor does not lose as much charge while triggering the triac, and produces a smaller hysteresis effect. As a result of the slower capacitor discharge through the trigger diode, however, the peak magnitude of the gate trigger current pulse is reduced. The size of the trigger capacitor may have to be increased to compensate for the reduction of the gate trigger current pulse.



	120VAC, 60Hz	240VAC, 60Hz
R_1	3.3kΩ, ½W	4.7kΩ, ½W
R_2	200kΩ, ½W	250kΩ, 1W
C	0.1µF, 200V	0.1µF, 400V
Y_1	T2800B	T2800D
Y_2	D3202U	D3202U

Fig. 5 – Single-time-constant light-dimmer circuit with series gate resistor.

The double-time-constant circuit in Fig. 6 improves on the performance of the single-time-constant control circuit. This circuit uses an additional RC network to extend the phase angle so that the triac can be triggered at small conduction angles. The additional RC network also minimizes the hysteresis effect. Fig. 7 shows the voltage waveforms for the ac supply and the trigger capacitor of the circuit of Fig. 6. Because of the voltage drop across R_3, the input capacitor C_2 charges to a higher voltage than the trigger capacitor C_3. When the voltage on C_3 reaches the breakover voltage of the trigger diode, the diode conducts and causes the capacitor to discharge and produce the gate current pulse to trigger the triac. After the trigger diode turns off, the charge on C_3 is partially restored by



	120VAC, 60Hz	240VAC, 60Hz
R1	2.2kΩ, ½W	3.3kΩ, ½W
R2	100kΩ, ½W	200kΩ, 1W
C1 C2	0.1μF, 200V	0.1μF, 400V
Y1	T2800B	T2800D
Y2	D3202U	D3202U

Fig. 6 – Double-time-constant light-dimmer circuit.

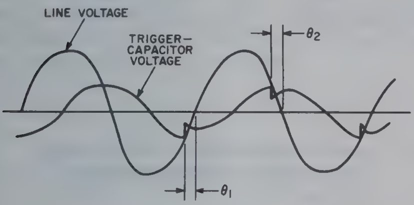
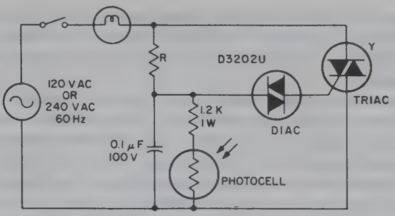


Fig. 7 – Voltage waveforms of double-time-constant control circuit.

the charge from the input capacitor C_2. The partial restoration of charge on C_3 results in better circuit performance with a minimum of hysteresis.

Light-Activated Control

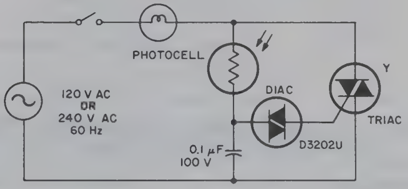
For applications requiring a light-activated circuit, such as outdoor lights or indoor night lights, the circuit shown in Fig. 8 can be employed. Although this circuit functions in the same manner as the light-dimming circuit, the photocell controls its operation. When the light impinges on the surface of the photocell, the resistance of the photocell becomes low and prevents the voltage on the trigger capacitor from increasing to the breakover voltage of the trigger diode. The circuit is then inoperative. When the light source is removed, the photocell becomes a high resistance. The voltage on the trigger capacitor then increases to the breakover voltage of the trigger diode and causes the diode to fire. The trigger pulse formed by the capacitor discharge through the trigger diode makes the triac conduct and operates the circuit. The triac continues to be triggered on each half-cycle and supplies power to the load as long as the resistance of the photocell is high. When light again impinges on the surface of the photocell and reduces its resistance, the voltage on the capacitor can no longer reach the breakover voltage of the trigger diode, and the circuit turns off.



	120VAC, 60Hz	240VAC, 60Hz
R	15kΩ, 2W	30kΩ, 3W
Y	T2800B	T2800D

Fig. 8 – Light Controlled Turn-Off Circuit.

For applications requiring operation when light impinges on the surface of the photocell, the circuit of Fig. 9 is recommended. In this circuit, low resistance of the photocell allows the triac to be triggered on. When light is removed from the photocell the increased resistance of the photocell prevents the triac from being triggered and renders the circuit inoperative.



	120VAC, 60Hz	240VAC, 60Hz
Y	T2800B	T2800D

Fig. 9 – Light Controlled Turn-On Circuit.

Radio Frequency Interference

The fast switching action of triacs when they turn on into resistive loads causes the current to rise to the instantaneous value determined by the load in a very short period of time. This fast switching action produces a current step which is largely composed of higher-harmonic frequencies that have an amplitude varying inversely as the frequency. In phase-control applications, such as light dimming, this current step is produced on each half-cycle of the input voltage. Because the switching occurs many times a second, a noise pulse is generated into frequency-sensitive devices such as AM radios and causes annoying interference. The amplitude of the higher frequencies in the current step is of such low levels that they do not interfere with television or FM radio.

There are two basic types of radio-frequency interference (RFI) associated with the switching action of triacs. One form, radiated RFI, consists of the high-frequency energy radiated through the air from the equipment. In most cases, this radiated RFI is insignificant unless the radio is located very close to the source of the radiation.

Of more significance is conducted RFI which is carried through the power lines and affects equipment attached to the same power lines. Because the composition of the current waveshape consists of higher frequencies, a simple choke placed in series with the load slows down the current rise time and reduces the amplitude of the higher harmonics. To be effective, however, such a choke must be quite large. A more effective filter, and one that has been found adequate for most light-dimming applications is shown in Fig. 10. The LC filter provides adequate attenuation of the high-frequency harmonics and reduces the noise interference to a low level.

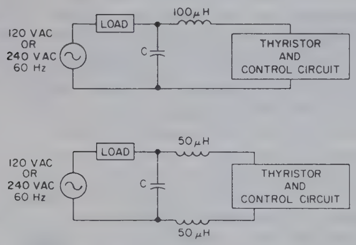


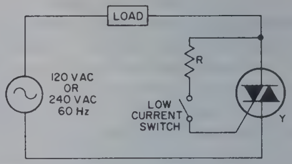
Fig. 10 – RFI-suppression networks: at 120 VAC, C = 0.1 μF, 200 V; at 240 VAC, C = 0.1 μF, 400 V.

Motor Control

Triacs can be used very effectively to apply power to motors and perform such functions as speed control, reversing, full power switching, or any other desired operating condition that can be obtained by a switching action. Because most motors are line-operated, the triac can be used as a direct replacement for electro-mechanical switches. In proper control circuits, triacs can change the operating characteristics of motors to obtain many different speed and torque curves.

A very simple triac static switch for control of ac motors is shown in Fig. 11. The low-current switch controlling the gate trigger current can be any type of transducer, such as a pressure switch, a thermal switch, a photocell, or a magnetic reed relay. This simple type of circuit allows the motor to be switched directly from the transducer switch without any intermediate power switch or relay.

For dc control, the circuit of Fig. 12 can be used. By use of the dc triggering modes, the triac can be directly triggered from transistor circuits by either a pulse or continuous signal.



	120VAC, 60Hz	240VAC, 60Hz
R	1kΩ, ½W	2kΩ, ½W
Y	T2700B	T2700D

Fig. 11 – Simple Triac Static Switch.

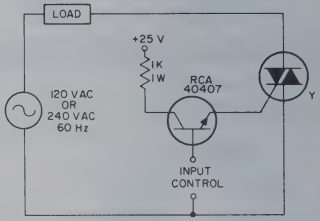
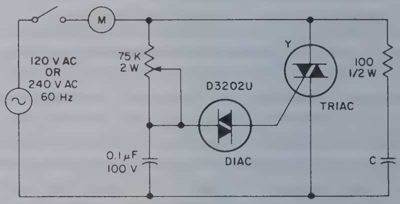


Fig. 12 – AC Triac Switch Control From DC Input: at 120 VAC, Y = T2700B; at 240 VAC, Y = T2700D.

Induction Motor Controls

Fig. 13 shows a single-time-constant circuit which can be used as a satisfactory proportional speed control for some applications and with certain types of induction motors, such as shaded pole or permanent split-capacitor motors, when the load is fixed. This type of circuit is best suited to applications which require speed control in the medium to full-power range. It is specifically useful in applications such as fans or blower-motor controls, where a small change in motor speed produces a large change in



	120VAC, 60Hz	240VAC, 60Hz
C	0.22μF, 200V	0.22μF, 400V
Y	T2700B	T2700D

Fig. 13 – Induction motor control.

air velocity. Caution must be exercised if this type of circuit is used with induction motors because the motor may stall suddenly if the speed of the motor is reduced below the drop-out speed for the specific operating condition determined by the conduction angle of the triac. Because the single-time-constant circuit cannot provide speed control of an induction motor load from maximum power to full off, but only down to some fraction of the full-power speed, the effects of hysteresis described previously are not present. Speed ratios as high as 3:1 can be obtained from the single-time-constant circuit used with certain types of induction motors.

Because motors are basically inductive loads and because the triac turns off when the current reduces to zero, the phase difference between the applied voltage and the device current causes the triac to turn off when the source voltage is at a value other than zero. When the triac turns off, the instantaneous value of input voltage is applied directly to the main terminals of the triac. This commutating voltage may have a rate of rise which can retrigger the triac. The commutating dv/dt can be limited to the capability of the triac by use of an RC network across the device, as shown in Fig. 13. The current and voltage waveshapes for the circuit are shown in Fig. 14 to illustrate the principle of commutating dv/dt.

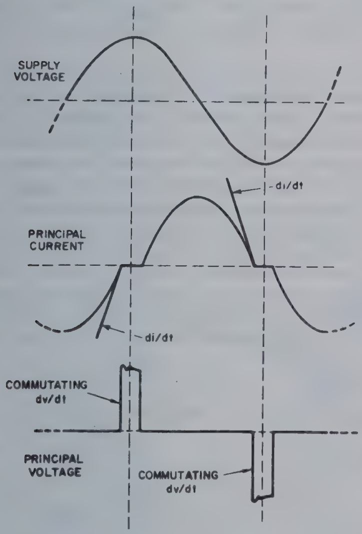
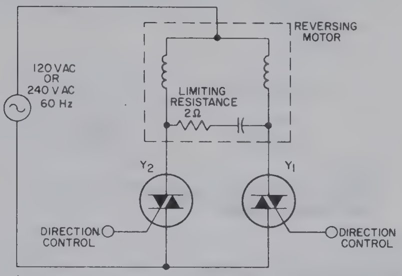


Fig. 14 — Waveshapes of commutating dv/dt characteristics.

Reversing Motor Control

In many industrial applications, it is necessary to reverse the direction of a motor, either manually or by means of an auxiliary circuit. Fig. 15 shows a circuit which uses two triacs to provide this type of reversing motor control. The reversing switch can be either a manual switch or an electronic switch used with some type of sensor to reverse the direction of the motor. A resistance is added in series with the capacitor to limit capacitor discharge current to a safe value whenever both triacs are conducting simultaneously. Simultaneous conduction can easily occur because the triggered triac remains in conduction after the gate is disconnected until the current reduces to zero. In the meantime, the nonconducting-triac gate circuit can be energized so that both triacs are ON and large loop currents are set up in the triacs by the discharge of the capacitor.

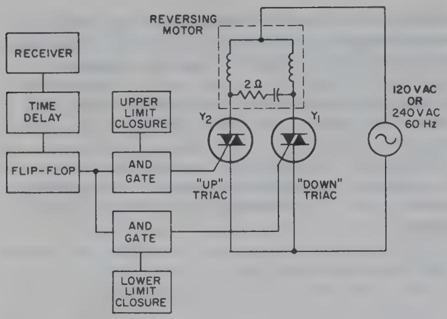


	120VAC, 60Hz	240VAC, 60Hz
Y_1	T2800B	T2800D
Y_2	T2800B	T2800D

Fig. 15 — Reversing motor control.

Electronic Garage-Door System

The triac motor-reversing circuit can be extended to electronic garage-door systems which use the principle of motor reversing for garage-door direction control. The system contains a transmitter, a receiver, and an operator to provide remote control for door opening and closing. The block diagram in Fig. 16 shows the functions required for a complete solid-state system. When the garage door is closed, the gate drive to the DOWN triac is disabled by the lower-limit closure and the gate drive to the UP triac is inactive because of the state of the flip-flop. If the transmitter is momentarily keyed, the receiver activates the time-delay monostable multivibrator so that it then changes the flip-flop state and provides continuous gate drive to the UP triac. The door then continues to travel in the UP direction until the upper-limit switch closure disables gate drive to the UP triac. A second keying of the transmitter provides the DOWN triac with gate drive and causes the door to travel in the DOWN direction until the gate drive is disabled by the lower limit closure. The time in which the monostable multivibrator is active should override normal transmitter keying for the purpose of eliminating erroneous firing. A feature of this system is that, during travel, transmitter keying provides motor reversing independent of the upper- or lower-limit closures. Additional features, such as obstacle obstructions, manual control, or time delay for overhead garage lights can be achieved very economically.

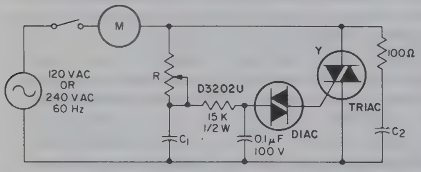

REVERSING MOTOR
RECEIVER
TIME DELAY
FLIP-FLOP
UPPER LIMIT CLOSURE
AND GATE
AND GATE
LOWER LIMIT CLOSURE
2 Ω
Y2
Y1
"UP" TRIAC
"DOWN" TRIAC
120 VAC OR 240 VAC 60 Hz

	120VAC, 60Hz	240VAC, 60Hz
Y_1	T2800B	T2800D
Y_2	T2800B	T2800D

Fig. 16 – Block diagram for remote-control solid-state garage-door systems.

Universal Motor Speed Controls

In applications in which the hysteresis effect can be tolerated or which require speed control primarily in the medium to full-power range, a single-time-constant circuit such as that shown in Fig. 13 for induction motors can also be used for universal motors. However, it is usually desirable to extend the range of speed control from full-power ON to very low conduction angles. The double-time-constant circuit shown in Fig. 17 provides the delay necessary to trigger the triac at very low conduction angles with a minimum of hysteresis, and also provides practically full power to the load at the minimum-resistance position of the control potentiometer. When this type of control circuit is used, an infinite range of motor speeds can be obtained from very low to full-power speeds.


M
120 VAC OR 240 VAC 60 Hz
R
D3202U
15 K 1/2 W
C_1
0.1μF 100 V
DIAC
Y
TRIAC
100Ω
C_2

	120VAC, 60Hz	240VAC, 60Hz
R	100kΩ, ½W	200kΩ, 1W
C_1	0.1μF, 200V	0.1μF, 400V
C_2	0.22μF, 200V	0.22μF, 400V
Y	T2700B	T2700D

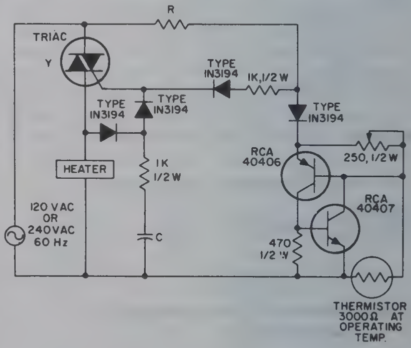
Fig. 17 – Universal Motor Speed Control.

Heat Control

There are three general categories of solid-state control circuits for electric heating elements: on-off control, phase control, and porportional control using integral-cycle synchronous switching. Phase-control circuits, such as those used for light dimming are very effective and efficient for electric heat control except for the problem of RFI. In higher-power applications, the RFI is of such magnitude that suppression circuits to minimize the interference become quite bulky and expensive.

An on-off circuit for the control of resistance-heating elements is shown in Fig. 18. The circuit also provides synchronous switching close to the beginning of the zero-voltage crossing of the input voltage to minimize RFI. The thermistor controls the operation of the two-transistor regenerative switch, which, in turn, controls the operation of the triac. When the temperature being controlled is low, the resistance of the thermistor is high and the regenerative switch is OFF. The triac is then triggered directly from the line on positive half-cycles of the input voltage. When the triac triggers and applies voltage to the load, the capacitor is charged to the peak value of the input voltage. The capacitor discharges through the triac gate to trigger the triac on the opposite half-cycle. The diode-resistor-capacitor "slaving" network triggers the triac on negative half-cycles of the ac input voltage after it is triggered on the positive half-cycle to provide integral cycles of ac power to the load.

When the temperature being controlled reaches the desired value as determined by the thermistor, the transistor regenerative switch conducts at the beginning of the positive input-voltage cycle to shunt the trigger current away from the triac gate. The triac does not conduct as long as the resistance of the thermistor is low enough to make the transistor regenerative switch turn on before the triac can be triggered.


R
TRIAC
Y
TYPE IN3194
1K, 1/2 W
TYPE IN3194
TYPE IN3194
TYPE IN3194
HEATER
1K 1/2 W
C
120 VAC OR 240VAC 60 Hz
RCA 40406
250, 1/2 W
RCA 40407
470 1/2 W
THERMISTOR 3000Ω AT OPERATING TEMP.

	120VAC, 60Hz	240VAC, 60Hz
R	2.2kΩ, 5W	3.9kΩ, 5W
C	0.5μF, 200V	0.5μF, 400V
Y	T4700B	T4700D

Fig. 18 – Synchronous switching on-off heat controller.

Proportional Integral-Cycle Control

On-off controls have only two levels of power input to the load. The heating coils are either energized to full power or are at zero power. Because of thermal time constants, on-off controls produce a cyclic action which alternates between thermal overshoots and undershoots with poor resolution.

This disadvantage is overcome and RFI is minimized by use of the concept of integral-cycle proportional control with synchronous switching. In this system, a time base is selected and the on-time of the triac is varied within the time base. The ratio of the on-to-off time of the triac within this time interval depends upon the power required to the heating elements to maintain the desired temperature. Fig. 19 shows the on-off ratio of the triac. Within the time period, the on-time varies by an integral number of cycles from full ON to a single cycle of input voltage.

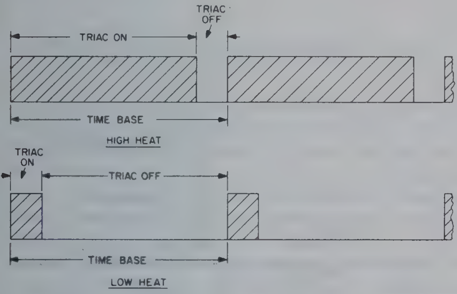

TRIAC OFF
TRIAC ON
TIME BASE
HIGH HEAT
TRIAC ON
TRIAC OFF
TIME BASE
LOW HEAT

Fig. 19 – Triac duty cycle.

One method of achieving integral cycle proportional control is to use a fixed-frequency sawtooth generator signal which is summed with a dc control signal. The sawtooth generator establishes the period or time base of the system. The dc control signal is obtained from the output of the temperature-sensing network. The principle is illustrated in Fig. 20. As the sawtooth voltage increases, a level is reached which turns on power to the heating elements. As the temperature at the sensor changes, the dc level shifts accordingly and changes the length of time that the power is applied to the heating elements within the established time.

When the demand for heat is high, the dc control signal is high and little power is supplied continuously to the heating elements. When the demand for heat is completely satisfied, the dc control signal is low and no power is supplied to the heating elements. Usually a system using this principle operates continuously somewhere between full ON and full OFF to satisfy the demand for heat.

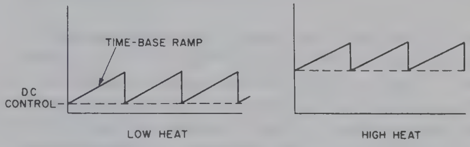

TIME-BASE RAMP
DC CONTROL
LOW HEAT
HIGH HEAT

Fig. 20 – Proportional-controller waveshapes.

A proportional integral-cycle heat control system is shown in Fig. 21. The ramp voltage is generated by charging of capacitor C through resistor R for approximately 2 seconds for the values shown. The length of the ramp is determined by the voltage magnitude required to trigger the regenerative switch consisting of Q_1 and Q_2. The temperature sensor consisting of Q_3 and Q_4, together with the controlling thermistor Th, establishes a voltage level at the base of Q_3 which depends upon the resistance value of the thermistor. Q_3 and Q_4 form a bistable multivibrator. The state of the multivibrator depends upon the base bias of Q_3. When Q_3 is conducting, Q_4 is cut off. The pulse generator is energized and generates pulses to trigger the triac. The output of the pulse generator is synchronized to the line voltage on the negative half-cycle by D_2 and R_3 and on the positive half-cycle by D_1 and R_3. The pulses are, therefore, generated at the zero-voltage crossings and trigger the triacs into conduction at only these points.

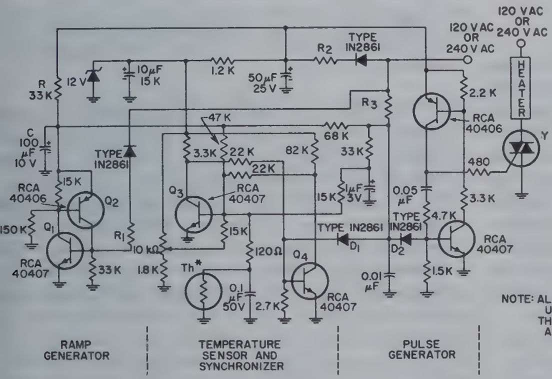

120 VAC OR 240 VAC
120 VAC OR 240 VAC
HEATER
TYPE IN2861
R2
1.2 K
R 33K
12 V
10µF 15 K
50µF 25 V
R3
2.2 K
RCA 40406
Y
C 100 µF 10 V
47 K
68 K
TYPE IN2861
3.3 K
22 K
22K
82 K
33 K
480
15 K
RCA 40406
Q2
Q3
RCA 40407
15K
1µF 3V
0.05 µF
3.3 K
TYPE IN2861
4.7 K
150 K
Q1
R1
15 K
TYPE IN2861
D1
D2
RCA 40407
10 kΩ
120Ω
Q4
RCA 40407
33 K
1.8 K
Th*
0.1 µF 50V
2.7 K
RCA 40407
0.01 µF
1.5 K
RAMP GENERATOR
TEMPERATURE SENSOR AND SYNCHRONIZER
PULSE GENERATOR

Fig. 21 – Proportional integral-cycle heat controller.

	120VAC, 60Hz	240VAC, 60Hz
R1	60kΩ, ½W	120kΩ, ½W
R2	3.3kΩ, 2W	5.6kΩ, 2W
R3	33kΩ,½W	57kΩ, ½W
Y	2N5441 or 2N5444	2N5442 or 2N5445

NOTE: ALL RESISTORS 1/2 W, ±10% UNLESS OTHERWISE SPECIF.
THERMISTOR APPROX. 3000 Ω AT OPERATING TEMP.

RCA
Solid State
Division

Thyristors
Application Note
AN-3778

Light Dimmers Using Triacs

by J. M. Neilson

Introduction

A simple, inexpensive light-dimmer circuit contains a diac, triac and RC charge-control network. The diac is a two-terminal ac switch which is changed from the non-conducting state to the conducting state by an appropriate voltage of either polarity. The triac is a three-terminal ac switch which is changed from the non-conducting state to the conducting state when a positive or negative voltage is applied to the gate terminal. This Note describes the use of the diac to trigger the triac in light-dimming circuits. The basic light-control circuit is introduced and its operation described. In addition, the various components added to improve circuit performance are discussed. Three complete circuits are shown, with tables showing the component values to be used for 120-volt, 60-Hz operation and 240-volt, 50/60 Hz operation. Mechanical details involved in building the circuits are also discussed and a trouble-shooting chart is included.

Circuit Description

The triac or bidirectional triode thyristor is a three-terminal solid-state switch. The two power electrodes or main terminals are referred to as T_1 and T_2, and the control electrode is referred to as the gate. Fig. 1 shows the voltage-current characteristic observed between the power electrodes. For either polarity of applied voltage, the device is bistable: the triac exhibits either a high impedance (off state) or a low impedance (on state). The device normally assumes the off state when bias is applied, but can be triggered into the on state by a pulse of current, of either polarity, applied between gate and T_1. The device then remains in
on state until current is reduced close to zero by
external circuitry.

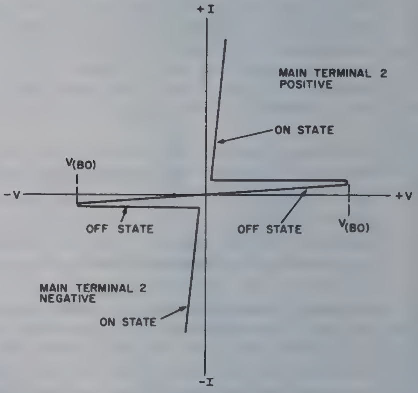


Fig.1 - Voltage-current characteristic of a triac.

The diac or symmetrical trigger diode is a two-t
minal bidirectional switch with a voltage-current ch
acteristic as shown in Fig. 2. The device exhibits
high-impedance, low-leakage-current characteristic
til the applied voltage reaches the breakover volta
V_{BO}, of the order of 35 volts. Above this voltage t
device exhibits a negative resistance, so that volta
decreases as current increases. In light-dimmer c
cuits a diac is used in conjunction with a capacitor

generate current pulses which trigger the triac into conduction. The voltage on the diac and capacitor increases until it reaches V_{BO}, at which point the diac voltage breaks back and a pulse of current flows as the capacitor discharges.

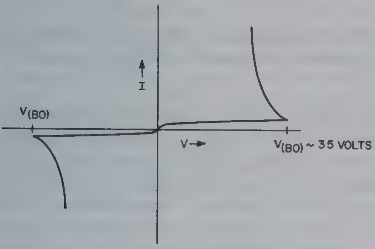


Fig.2 - Voltage-current characteristic of a diac.

Fig. 3 shows the basic triac-diac light control circuit with the triac connected in a series with the load. During the beginning of each half cycle the triac is in the off-state. As a result, the entire line voltage appears across the triac, and none appears across the load. Because the triac is in parallel with the potentiometer and capacitor, the voltage across the triac drives current through the potentiometer and charges the capacitor. When the capacitor voltage reaches the breakover voltage V_{BO} of the diac, the capacitor discharges through the triac gate, turning on the triac. At this point, the line voltage is transferred from the triac to the load for the remainder of that half cycle. This sequence of events is repeated for every half cycle of either polarity. If the potentiometer resistance is reduced, the capacitor charges more rapidly and V_{BO} is reached earlier in the cycle, increasing the power applied to the load and hence the intensity of light. If the potentiometer resistance is increased, triggering occurs later, load power is reduced, and the light intensity is decreased.

Although the basic light-control circuit operates with the component arrangement shown in Fig. 3, additional components and sections are usually added to reduce hysteresis effects, extend the effective range of the light-control potentiometer, and suppress radio-frequency interference.

Hysteresis

As applied to light controls, the term hysteresis refers to a difference in the control potentiometer setting at which the light initially turns-on and the setting at which it is extinguished. With high hysteresis, the control may have to be turned across 35 per cent of its range before the light turns on at all, after which the control must be turned back to a much lower setting before the light goes completely out.

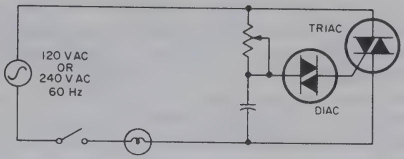


Fig.3 - Basic triac-diac light-control circuit.

Besides poor control, hysteresis is undesirable because at low illumination levels, the light may be extinguished by a momentary drop in line voltage. At low illumination levels, the potentiometer is normally turned back beyond the setting at which it initially turned on. When triggering is missed on one half cycle as a result of a momentary drop in line voltage such as that caused by starting a heavy appliance, oil burner, etc., the light may go out and stay out until the control is again turned up to the starting point.

Hysteresis is caused by an abrupt decrease in capacitor voltage when triggering begins. Fig. 4 shows the charging cycle of the capacitor-diac circuit. The large ac sine wave represents the line voltage; the smaller ac sine wave represents the normal charging cycle of the capacitor. Gate triggering occurs at the first point of intersection of the two waves. At this point, however, there is an abrupt decrease in the capacitor voltage (dashed line). As a result, the capacitor begins to charge during the next half cycle at a lower voltage and reaches the trigger voltage in the opposite direction earlier in the cycle (2nd (Actual) Gate Trigger Point). Hysteresis is reduced by maintaining some voltage on the capacitor during gate triggering.

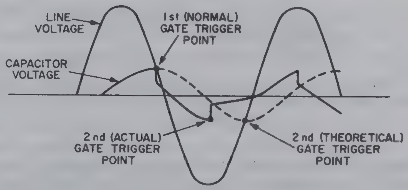


Fig.4 - Charging cycle of the capacitor-diac network in the circuit of Fig.3.

Some improvement is realized when a resistor is connected in series with the diac, as shown in Fig. 5. Although this positive resistance reduces the net amount of negative resistance so the capacitor voltage does not drop as much, it also decreases the magnitude

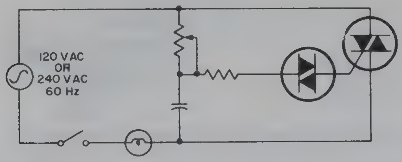


Fig.5 - Light-control circuit incorporating a resistor in series with the diac.

of the gate current pulse, and therefore, a larger-value capacitor may be required. More significant improvement is obtained when a second capacitor is added as shown in Fig. 6, forming a "double-time-constant" circuit.

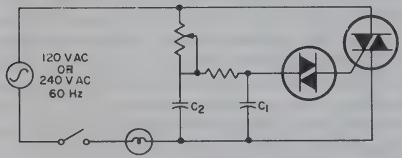


Fig.6 - "Double-time-constant" light-control circuit.

The added capacitor C_2 reduces hysteresis by charging to a higher voltage than C_1, and maintaining some voltage on C_1 after triggering. The effect is illustrated in Fig. 7. As gate triggering occurs C_1 discharges to form the gate current pulse. However, because of the longer C_2 R time constant, C_2 restores some of the charge removed from C_1 by the gate current pulse.

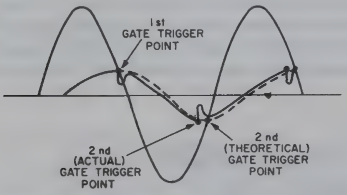


Fig.7 - Charging cycle of the diac network in the circuit of Fig.6.

Fig. 8 shows another double-time constant circuit in which a fixed resistor is added and the potentiometer is moved over to connect directly to the diac. Although the maximum attainable conduction angle is increased, the difference in power is less than one per cent.

Range Control

Maximum range of light control is obtained when the lamp begins to light as soon as the potentiometer is turned slightly from the zero-intensity end of the range.

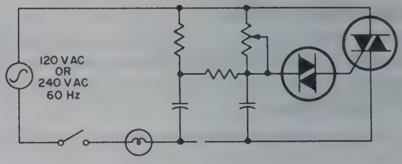


Fig.8 - Double-time-constant circuit in which the potentiometer is connected directly to the diac.

After the control circuit is assembled, the point of initial turn-on may be located at 40 per cent across the control range, leaving only 60 per cent effective to control the light intensity. This difference occurs because the point of initial turn-on is determined by the interaction of three components (potentiometer, capacitor, and diac) each of which may have values with a tolerance of plus or minus 20 per cent. A trimmer resistor connected across the potentiometer, as shown in Fig. 9, can be used to compensate for component variations and move the initial turn-on point back to the end of the control range. The trimmer can be a variable resistor which is set to the required value after the circuit is assembled, or a fixed resistor of the required value as determined by individually testing the assemblies with a resistor substitution box in place of the trimmer.

The double-time-constant circuit with trimmer resistor provides consistently good hysteresis correction as well as good range control. The use of a high-resistance potentiometer, possibly about twice the resistance of the trimmer, spreads out the low-intensity range for finer control.

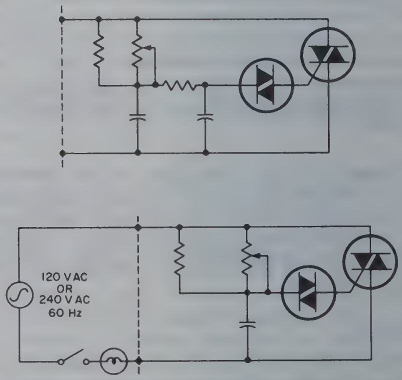


Fig.9 - Light-control circuits incorporating a trimmer resistor across the potentiometer.

RFI Suppression

Because the triac switches from the high-impedance state to the low-impedance state within 1 or 2 microseconds, the current must rise from essentially zero to whatever the load will permit within this period. This rapid rise in current produces radio frequency interference (RFI) extending up into the range of several megahertz. Although the resulting noise does not affect the television and FM radio frequencies, it does affect the short-wave and AM-radio bands. The level of RFI produced by the triac is well below that produced by most AC-DC brush-type electric motors, but because the light dimmer may be on for long periods of time, some type of RFI suppression network is usually added. A reasonably effective suppression network is obtained, as shown in Fig. 10, by connection of an inductor in series with the light-control circuit to limit the rate of current rise. The capacitor is connected across the entire network to bypass high-frequency signals so that they are not connected to any external circuits through the power lines.

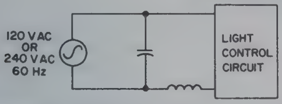


Fig.10 - RFI-suppression network.

Overload Considerations

An important consideration in the choice of a triac is the transient load which results from the initially lower resistance of the cold filament when the lamp is first turned on. The transient load results in a surge or inrush current which can destroy the triac. The worst case occurs when the light is switched on at the peak of the line voltage. The ratio of initial peak current to steady-state current is usually about 10 to 1 and can be as high as 15 to 1 for high-wattage lamps. The triac chosen for a particular lamp, therefore, should have a subcycle surge capability sufficient to allow repeated passage of this peak current without degradation of the device.

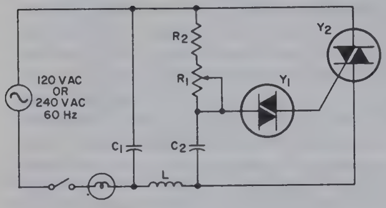
Flashover is another transient condition associated with incandescent loads, and may impose an even greater stress than inrush. Flashover refers to the arc developed between the broken ends of the filament when the light bulb burns out. Ionization within the bulb allows the arc to flow directly between the internal lead-in wires, and current is then limited only by line impedance. Because of the large currents associated with flashover, incandescent light bulbs have fuses built into the stem to open circuit at the bulb without opening the line circuit breaker. On low-wattage bulbs, the arc frequently self-extinguishes as line voltage goes through zero, so the surge duration is less than one half cycle. On higher-wattage bulbs, however, the arc often continues until the bulb fuse opens, and may last for somewhat more than one half cycle. Damage or degradation of the triac can be avoided by selection of a triac that has surge capability in excess of the flashover currents which can occur. A device capable of handling a one-cycle peak current of 100 amperes or more is adequate for most installations using up to 150-watt bulbs. When the triac has inadequate surge capability for a particular application, special high-speed fuses or circuit breakers, external resistors, or other current limiting devices such as chokes may be used.

Light-Dimmer Circuits

Fig. 11 shows a single-time-constant circuit; Fig. 12 shows a double-time-constant circuit. Both are complete circuits suitable for operation at 120 or 240 volts ac, 50 or 60 Hz. The chart with each circuit specifies the values of components which change with the line voltage. The resistor in series with the potentiometer in each circuit is used to protect the potentiometer by limiting the current when the potentiometer is at the low-resistance end of its range.

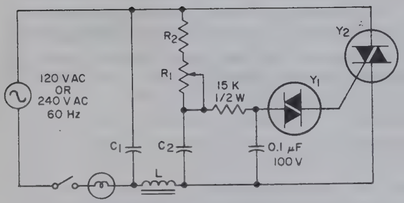
It is important to remember that a triac in these circuits dissipates power at the rate of about one watt per ampere. Therefore, some means of removing heat must be provided to keep the device within its safe operating-temperature range. On a small light-control circuit such as one built into a lamp socket, the lead-in wire serves as an effective heat sink. Attachment of the triac case directly to one of the lead-in wires provides sufficient heat dissipation for operating currents up to 2 amperes (rms). On wall-mounted controls operating up to 6 amperes, the combination of face plate and wallbox serves as an effective heat sink. For higher-power controls, however, the ordinary face plate and wallbox do not provide sufficient heat-sinking area. In this case, additional area may be obtained by use of a finned face plate that has a cover plate which stands out from the wall so air can circulate freely over the fins.

On wall-mounted controls, it is also important that the triac be electrically isolated from the face plate, but at the same time be in good thermal contact with it. Although the thermal conductivity of most electrical insulators is relatively low when compared with metals, a low-thermal-resistance, electrically isolated bond of triac to face plate can be obtained if the thickness of


120 VAC
OR
240 VAC
60 Hz
R2
R1
Y2
Y1
C1
C2
L

	120 VAC, 60 Hz	240 VAC, 50/60 Hz
R_1	0.25 megohm, ½W	0.25 megohm, 1W
R_2	3300 ohms, ½W	4700 ohms, ½W
C_1	0.05 μF, 100V	0.1 μF, 100V
C_2	0.05 μF, 100V	0.10 μF, 100V (60 Hz) 0.12 μF, 100V (50 Hz)
L	100 μH	200 μH
Y_1	D3202U	D3202U
Y_2	T2800B	T2800D

Fig.11 - Single-time-constant light-dimmer circuit.


120 VAC
OR
240 V AC
60 Hz
R2
R1
15 K
1/2 W
Y2
Y1
C1
C2
L
0.1 μF
100 V

	120 VAC, 60 Hz	240 VAC, 50/60 Hz
R_1	0.1 megohm, ½W	0.2 megohm, 1W (60 Hz) 0.25 megohm, 1W (50 Hz)
R_2	2200 ohms, ½W	3300 ohms, ½W
C_1C_2	0.1 μF, 200V	0.1 μF, 400V
L	100 μH	200 μH
Y_1	D3202U	D3202U
Y_2	T2800B	T2800D

Fig.12 - Double-time-constant light-dimmer circuit.

the insulator is minimized, and the area for heat transfer through the insulator is maximized. Suitable insulating materials are fiber-glass tape, ceramic sheet, mica, and polyimide film. Fig. 13 shows two examples of isolated mounting for triacs: in Fig. 13(a), a TO-5 package; in Fig. 13(b), the new plastic package. Electrical insulating tape is first placed over the inside of the face plate. The triac is then mounted to the insulated face plate by use of epoxy-resin cement.

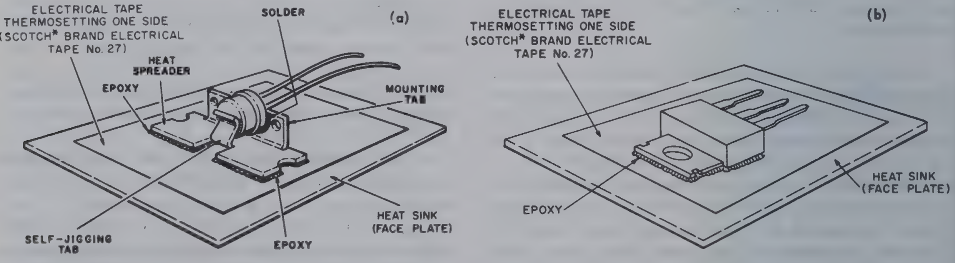

(a)
ELECTRICAL TAPE
THERMOSETTING ONE SIDE
(SCOTCH* BRAND ELECTRICAL
TAPE No. 27)
SOLDER
HEAT
SPREADER
EPOXY
MOUNTING
TAB
SELF-JIGGING
TAB
EPOXY
HEAT SINK
(FACE PLATE)
(b)
ELECTRICAL TAPE
THERMOSETTING ONE SIDE
(SCOTCH* BRAND ELECTRICAL
TAPE No. 27)
EPOXY
HEAT SINK
(FACE PLATE)

Fig.13 - Examples of isolated mounting of triacs.

Trouble Shooting

Some malfunctions which can occur in light-dimming circuits are listed with their possible causes, as follows:

	Component	Possible Cause
Light remains on full intensity and will not dim.	Triac	Shorted in both directions caused by flashover or high current surge.
	Wiring	Anode-cathode or anode-gate shorted.
Light intensity can be varied but fails to reach zero.	Triac	Breakover voltage reduced in one or both directions.
	Diac	Low breakover voltage.
	Triggering Capacitor	Capacitance too low.
	Potentiometer	Maximum resistance too low.
Discontinuity in brightness at about half intensity.	Triac	I_{GT} too nigh in one mode.
	Diac	Breakover not symmetrical.
Flickering exists at low intensity.	Triac	Low commutating $dv/_{dt}$ capability. Flickering stops when the inductor is shorted.
Light out over most of the control range; turns on full intensity near low resistance end of potentiometer.	Triac	I_{GT} too high.
	Diac	Voltage breakback too low.
	Wiring	Diac not included or shorted out.
Same effect as preceding, but accompanied by arcing in potentiometer.	Triac	Internal short gate to cathode (very unlikely because such devices are rejected by 100 per cent electrical test).
	Capacitor	Shorted (this condition destroys the potentiometer, but not the triac).
	Wiring	Open anode contact (this condition destroys both the potentiometer and the triac). Cathode to gate short (this condition destroys only the potentiometer).
Light fails to turn on at all.	Triac	Open gate contact (very unlikely due to the 100 per cent electrical test by manufacturer).
	Diac	Open
	Potentiometer	Open
	Wiring	Open circuit at potentiometer, diac, triac gate, or cathode.

A New Horizontal-Deflection System Using RCA S3705M and S3706E Silicon Controlled Rectifiers

This Note describes a highly reliable horizontal-deflection system designed for use in the RCA CTC-40 solid-state color television receiver. This system illustrates a new approach in horizontal-circuit design that represents a complete departure from the approaches currently used in commercial television receivers. The switching action required to generate the scan current in the horizontal yoke windings and the high-voltage pulse used to derive the dc operating voltages for the picture tube is controlled by two silicon controlled rectifiers (SCR's) that are used in conjunction with associated fast-recovery diodes to form bipolar switches.

The RCA-S3705M SCR used to control the trace current and the RCA-S3706E SCR that provides the commutating action to initiate trace-retrace switching exhibit the high voltage- and current-handling capabilities, together with the the excellent switching characteristics, required for reliable operation in deflection-system applications. The switching diodes, RCA-D2601M (trace) and D2601E (commutating), provide fast recovery times, high reverse-voltage blocking capabilities, and low turn-on voltage drops. These features and the fact that, with the exception of one non-critical triggering pulse, all control voltages, timing, and control polarities are supplied by passive elements within the system (rather than by external drive sources) contribute substantially to the excellent reliability of the SCR deflection system.

SYSTEM PERFORMANCE

Fig. 1 shows the circuit configuration of the over-all horizontal-deflection system. The system operates directly from a conventional, unregulated dc power supply of +155 volts, provides full-screen deflection at angles up to 90 degrees at full beam current (1.5 milliamperes average in the CTC-40 receiver). The current and voltage waveforms required for horizontal deflection and for generation of the high voltage are derived essentially from LC resonant circuits. As a result, fast and abrupt switching transients, which would impose strains on the solid-state devices, are avoided.

A regulator stage is included in the SCR horizontal-deflection circuit to maintain the scan and the high voltage within acceptable limits with variations in the ac line voltage or picture-tube beam current. The system also contains circuits that provide full protection against the effects of arcs in the picture tube or the high-voltage rectifier and linearity and pincushion correction circuits. Each individual part of the deflection system is designed to specifications that are compatible with achievement of the following system performance:

Picture Tube

25-inch, 90-degree color type; neck diameter = 1$\frac{7}{16}$ inches (i.e., similar to RCA-Type 25XP22)

Ultor Voltage, Beam Current, and Regulation

26.5 kilovolts at zero beam current or 24.5 kilovolts at 1.5 milliamperes (average) of beam current for ac line voltages of 120 to 130 volts rms

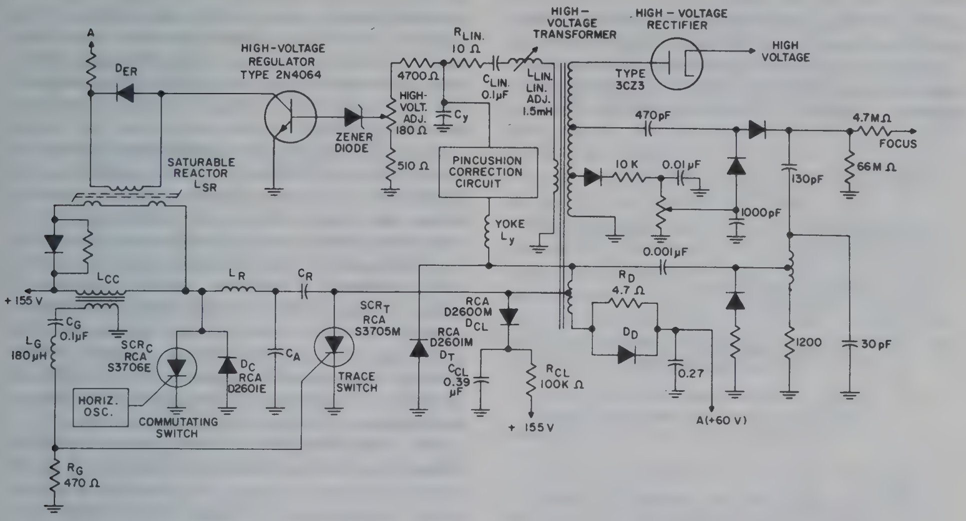

A
D_ER
HIGH-VOLTAGE REGULATOR TYPE 2N4064
R_LIN. 10 Ω
HIGH-VOLTAGE TRANSFORMER
HIGH-VOLTAGE RECTIFIER
HIGH VOLTAGE
TYPE 3CZ3
4700 Ω
C_LIN. 0.1µF
L_LIN. LIN. ADJ. 1.5mH
HIGH-VOLT. ADJ. 180 Ω
C_y
ZENER DIODE
510 Ω
PINCUSHION CORRECTION CIRCUIT
SATURABLE REACTOR L_SR
470pF
4.7MΩ
FOCUS
10 K
0.01µF
66 MΩ
130pF
1000pF
YOKE L_y
0.001µF
L_CC
L_R
C_R
+155 V
R_D 4.7 Ω
SCR_T RCA S3705M
RCA D2600M D_CL
C_G 0.1µF
L_G 180µH
SCR_C RCA S3706E
RCA D2601M D_T
D_D
1200
30pF
D_C RCA D2601E
C_A
TRACE SWITCH
C_CL 0.39 µF
R_CL 100K Ω
0.27
HORIZ. OSC.
COMMUTATING SWITCH
+ 155V
A(+60 V)
R_G 470 Ω

Fig. 1 — General circuit configuration of the over-all SCR horizontal-deflection system.

24.5 kilovolts at 1 milliampere of beam current for ac line voltages of 108 to 130 volts rms

22.5 kilovolts at 1.5 milliamperes of beam current for an ac line voltage of 105 volts rms

Input Current

420 milliamperes at zero beam current

670 milliamperes at 1.5 milliamperes of beam current

DC Input Voltage (Nominal)

155 volts at zero beam current

148 volts at 1.5 milliamperes of beam current

Scan Regulation*

¼-inch change for variation in ac line voltage from 105 to 130 volts rms

¼-inch change for beam-current variation of 0.3 to 1.5 milliamperes at a line voltage of 120 volts rms

Linearity*

Deviation in picture width is equal to or less than 5 per cent, left to right

Retrace Time

Flyback pulse width = 12.5 microseconds at zero crossing of yoke voltage

Total flyback pulse width = 14 microseconds at extremes of yoke voltage

Trigger Input

10-volt, 5-microsecond pulse (obtained directly from horizontal oscillator)

Pincushion Correction

Top and bottom pincushion correction provided for a minimum radius of 150 inches

REQUIREMENTS OF THE SWITCHING SCR's AND DIODES

The SCR horizontal-deflection circuit requires fast reverse recovery for both the switching SCR's and the diodes and fast turn-on for the SCR's. The S3705M and S3706E SCR's and the D2601M and D2601E diodes are well suited to provide this type of performance. (Detailed specifications for the SCR's and diodes are given in the published data on the devices). The exceptional capabilities of these devices are illustrated by the performance that they provide in the horizontal-deflection system. Fig. 2 shows the significant current and voltage waveforms that the SCR's and diodes are subjected to during operation of the deflection circuit.

The S3706E SCR used in the commutating switch is required to pass a pulse of current that has a peak amplitude of 13 amperes and an initial rate of rise of 20 amperes per microsecond. At the operating frequency of the horizontal-deflection circuit, achievement of this performance requires low turn-on dissipation in the SCR. The turn-on dissipation in the S3705M SCR used in the trace switch is also low because of the waveform of the current that flows through the device.

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* The deflection system is not subject to degradation of scan or linearity during component life.

An SCR is turned off by a reversal of its anode-to-cathode voltage; before the forward voltage can be reapplied, a short time is required to allow the device to regain its forward-blocking capability. Under worst-case conditions, the available turn-off time for the commutating switch requires the use of an SCR that can be completely turned off in 4.5 microseconds. The SCR must then be able to block a reapplied forward voltage of 100 volts applied at a rate of 400 volts per microsecond. The turn-off requirement for the trace-switch SCR, under worst-case circuit conditions, is 2.5 microseconds. This device is then required to block a reapplied forward voltage of 400 volts at a rate of 175 volts per microsecond. Negative gate bias is used with both SCR's to reduce turn-off time. The gate sensitivity of the commutating-switch SCR is high enough so that this device can be triggered directly from the horizontal oscillator.

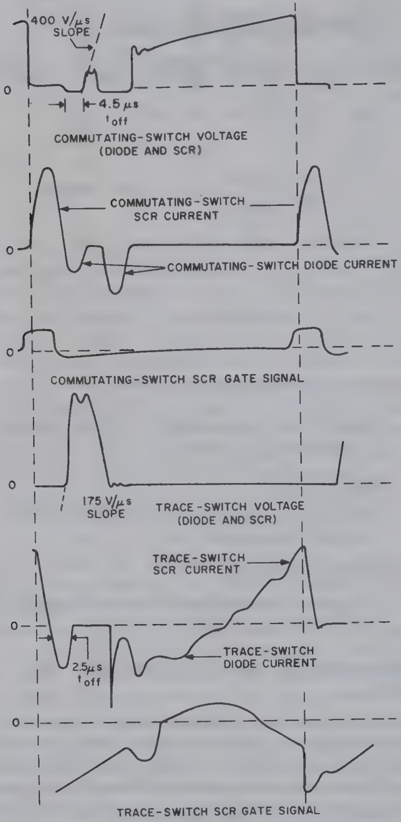


Fig. 2 — Voltage and current waveforms applied to the SCR's and diodes used to control the switching actions in the SCR horizontal-deflection system.

The exceptional switching performance provided by the S3705M and S3706E SCR's is made possible by use of all-diffused pellet structures that employ a centrally located gate having a large gate-cathode periphery to ensure low initial forward voltage drops and, therefore, low switching losses. The lifetime of minority charge carriers is substantially reduced to provide the fast turn-off-time capability. The "shorted-emitter" construction technique, in which a low-resistance path is provided around the gate-to-cathode junction, is used to obtain the high dv/dt capability required for the SCR's to withstand the high rates of reapplied forward voltage encountered in the horizontal-deflection system.

The D2601M and D2601E diodes used in the trace and commutating switches, respectively, are designed to provide fast reverse recovery (by means of minority-carrier lifetime control), to reduce rf interference in the circuit, and to decrease diode recovery losses. The slope and magnitude of the reverse-recovery current in the diodes have been optimized to ensure minimum reverse-recovery dissipation and to prevent rf interference because of overly abrupt recovery. The fast recovery characteristics have been achieved while maintaining a low turn-on voltage drop and a high reverse-voltage blocking capability.

OPERATION OF THE BASIC DEFLECTION CIRCUIT

The essential components in the SCR horizontal-deflection system required to develop the scan current in the yoke windings are shown in Fig. 3. Essentially

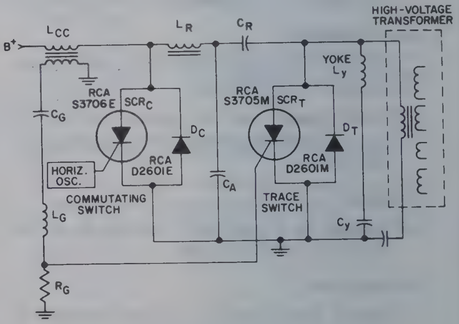


Fig. 3 — Basic circuit for generation of the deflection-current waveform in the horizontal yoke winding.

the trace-switch diode D_T and the trace-switch controlled rectifier SCR_T provide the switching action which controls the current in the horizontal yoke windings L_y during the picture-tube beam-trace interval. The commutating-switch diode D_C and the commutating-switch controlled rectifier SCR_C initiate retrace and control the yoke current during the retrace interval. Inductor L_R and capacitors, C_R, C_A, and C_y provide the necessary energy storage and timing cycles. Inductor L_{CC} supplies a charge path for capacitor C_R from the dc supply voltage (B+) so that the system can be recharged from the receiver power supply. The secondary of inductor L_{CC}, provides the gate trigger voltage for the trace-switch SCR. Capacitor C_R establishes the optimum retrace time by virtue of its resonant action with inductor L_R.

The complete horizontal-deflection cycle may best be described as a sequence of discrete intervals, each terminated by a change in the conduction state of a switching device. In the following discussion, the action of the auxiliary capacitor C_A and the flyback high-voltage transformer are initially neglected to simplify the explanation.

First Half of the Trace Interval

Fig. 4 shows the circuit elements involved and the voltage and current relationships during the first half of the trace deflection-current interval, the period from T_0 to T_2. At time T_0, the magnetic field has been established about the horizontal yoke windings L_y by the circuit action during the retrace period of the preceding cycle (explained in the subsequent discussion of retrace intervals). This magnetic field generates a decaying yoke current i_y that decreases to zero when the energy in the yoke winding is depleted (at time T_2). This current charges capacitor C_y to a positive voltage V_{C_y} through the trace-switch diode D_T.

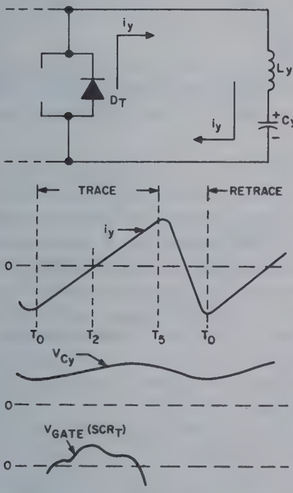


Fig. 4 — Effective configuration of the deflection circuit during the first half of the trace interval, time T_0 to T_2, and operating voltage and current waveforms for the complete trace-retrace cycle.

During the first half of the trace interval (just prior to time T_2) the trace controlled rectifier SCR_T is made ready to conduct by application of an appropriate gate voltage pulse V_{GATE}. SCR_T does not conduct, however, until a forward bias is also applied between its anode and cathode. This voltage is applied during the second half of the trace interval.

Second Half of the Trace Interval

At time T_2, current is no longer maintained by the yoke inductance, and capacitor C_y begins to discharge into this inductance. The direction of the current in the circuit is then reversed, and the trace-switch diode D_T becomes reverse-biased. The trace-switch controlled rectifier SCR_T, however, is then forward-biased by the voltage V_{C_y} across the capacitor, and the capacitor discharges into the yoke inductance through SCR_T, as indicated in Fig. 5. The capacitor C_y is sufficiently large so that the voltage V_{C_y} remains essentially constant during the entire trace and retrace

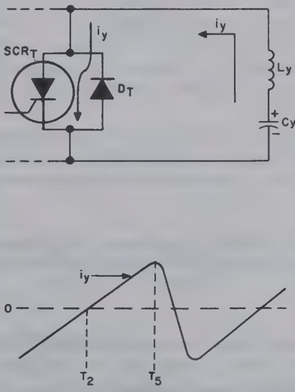


Fig. 5 — Effective configuration of the deflection circuit during the second half of the trace interval, time T_2 to T_5, and the complete scan-current waveform.

cycle. This constant voltage results in a linear rise in current through the yoke inductance L_y over the entire scan interval from T_0 to T_5.

Start of the Retrace Interval

The circuit action to initiate retrace starts before the trace interval is completed. Fig. 6 shows the circuit elements and the voltage and current waveforms required for this action. At time T_3, prior to the end of the trace period, the commutating-switch controlled rectifier SCR_C is turned on by application of a pulse from the horizontal oscillator to its gate. Capacitor C_R is then allowed to discharge through SCR_C and inductor L_R. The current in this loop, referred to as the commutating circuit, builds up in the form of a half-sine-wave pulse. At time T_4, when the magnitude of this current pulse exceeds the yoke current, the trace-switch diode D_T again becomes forward-biased. The excess current in the commutating pulse is then bypassed around the yoke winding by the shunting action of diode D_T. During the time from T_4 to T_5, the trace-switch controlled rectifier SCR_T is reverse-biased by the amount of the voltage drop across diode D_T. The trace-switch controlled rectifier, therefore, is turned off during this interval and is allowed to recover its ability to block the forward voltage that is subsequently applied.

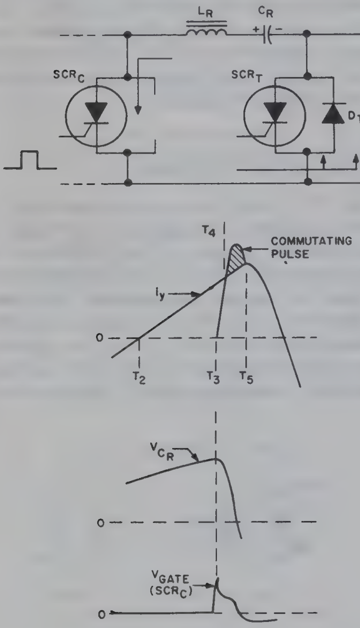


Fig. 6 — Effective configuration of the deflection circuit and significant voltage and current waveforms for initiation of retrace, time T_3 to T_5.

First Half of the Retrace Interval

At time T_5, the commutating pulse is no longer greater than the yoke current, as shown in Fig. 7; trace-switch diode D_T then ceases to conduct. The yoke inductance maintains the yoke current but, with SCR_T in the OFF state, this current now flows in the commutating loop formed by L_R, C_R, and SCR_C. Time T_5 is the beginning of retrace.

As the current in the yoke windings decreases to zero, the energy supplied by this current charges capacitor C_R with an opposite-polarity voltage in a resonant oscillation. At time T_6, the yoke current is zero, and capacitor C_R is charged to its maximum negative voltage value. This action completes the first half of retrace.

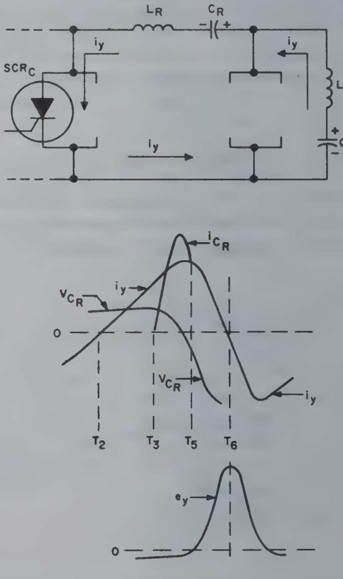


Fig. 7 — Effective configuration of the deflection circuit and operating voltage and current waveforms during the first half of retrace, time T_5 to T_6.

Second Half of the Retrace Interval

At time T_6, the energy in the yoke inductance is depleted, and the stored energy on the retrace capacitor C_R is then returned to the yoke inductance. This action reverses the direction of current flow in the yoke. During the reversal of yoke current, the commutating-switch diode D_C provides the return path for the loop current, as indicated in Fig. 8. The commutating-switch controlled rectifier SCR_C is reverse-biased by the amount of the voltage drop across diode D_C. The commutating-switch controlled rectifier, therefore, turns off and recovers its voltage-blocking capability. As the yoke current builds up in the negative direction, the voltage on the retrace capacitor C_R is decreased. At time T_0, the voltage across capacitor C_R no longer provides a driving voltage for the yoke current to flow in the loop formed by L_R, C_R, and L_y. The yoke current finds an easier path up through trace-switch diode D_T, as shown in Fig. 9. This action represents the beginning of the trace period for the yoke current (i.e., the start of a new cycle of operation), time T_0.

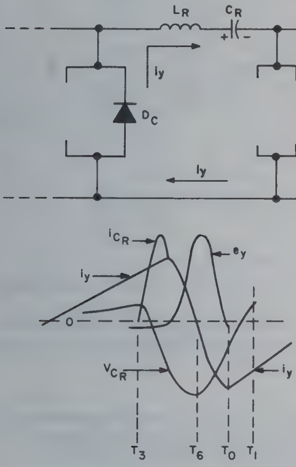


Fig. 8 — Effective configuration of the deflection circuit and operating voltage and current waveforms during the second half of retrace, time T_6 to T_0.

Once the negative yoke current is decoupled from the commutating loop by the trace-switch diode, the current in the commutating circuit decays to zero. The stored energy in the inductor L_R charges capacitor C_R to an initial value of positive voltage. Because the resonant frequency of L_R and C_R is high, this transfer is accomplished in a relatively short period, T_0 to T_1, as shown in Fig. 8.

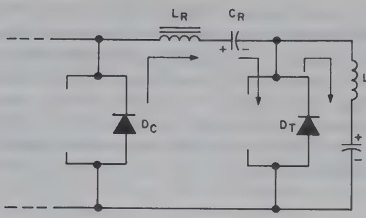


Fig. 9 — Effective configuration of the deflection circuit during the switchover from retrace to trace, time T_0.

Recharging and Resetting Actions

The actions required to restore energy to the commutating circuit and to reset the trace SCR are also very important considerations in the operation of the basic deflection circuit. Both actions involve the inductor L_{CC}.

During the retrace period, inductor L_{CC} is connected between the dc supply voltage (B+) and ground by the conduction of either the commutating-switch SCR or diode (SCR_C or D_C), as indicated in Fig. 10. When the diode and the SCR cease to conduct, however, the path from L_{CC} to ground is opened. The energy stored in inductor L_{CC} during the retrace interval then charges capacitor C_R through the B+ supply, as shown in Fig. 11. This charging process continues through the trace period until retrace is again initiated. The resultant charge on capacitor C_R is used to resupply energy to the yoke circuit during the retrace interval.

The voltage developed across inductor L_{CC} during the charging of capacitor C_R is used to forward-bias the gate electrode of the trace SCR properly so that this

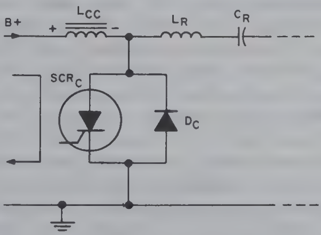


Fig. 10 — Circuit elements and current path used to supply energy to the charging choke Lcc during period from the start of retrace switching action to the end of the first half of the retrace interval, time T_3 to T_1.

device is made ready to conduct. This voltage is inductively coupled from L_{CC} and applied to the gate of SCR_T through to a wave-shaping network formed by inductor L_G, capacitor C_G, and resistor R_G. The resulting voltage signal applied to the gate of SCR_T has the desired shape and amplitude so that SCR_T conducts when a forward bias is applied from anode to cathode, approximately midway through the trace interval.

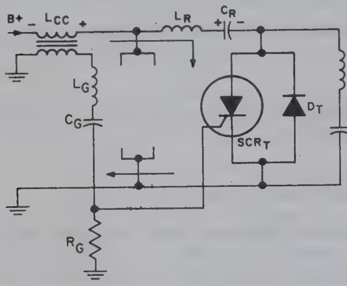


Fig. 11 — Effective configuration of the deflection circuit for resetting (application of forward bias to) the trace SCR and recharging the retrace capacitor C_R, during time interval from T_1 to T_3.

Effect of Auxiliary Capacitor C_A

In the preceding discussions of the operation of the deflection circuit, the effect of capacitor C_A was neglected. Inclusion of this capacitor affects some of the circuit waveforms, as shown in Fig. 12, aids in the turn-off of the trace SCR, reduces the retrace time, and provides additional energy-storage capability for the circuit.

During most of the trace interval (from T_0 to T_4), including the interval (T_3 to T_4) during which the commutating pulse occurs, the trace switch is closed, and capacitor C_A is in parallel with the retrace capacitor C_R. From the start of retrace at time T_4 to the beginning of the next trace interval at time T_0, the trace switch is open. For this condition, capacitor C_A is in series with the yoke L_y and the retrace capacitor C_R so that the capacitance in the retrace circuit is effectively decreased. As a result, the resonant frequency of the retrace is increased, and the retrace time is reduced.

The auxiliary capacitor C_A is also in parallel with the retrace inductor L_R. The waveshapes in the deflection circuit are also affected by the resultant higher-frequency resonant discharge around this loop. The voltage and current waveforms shown in Fig. 12 illustrate the effects of the capacitor C_A.

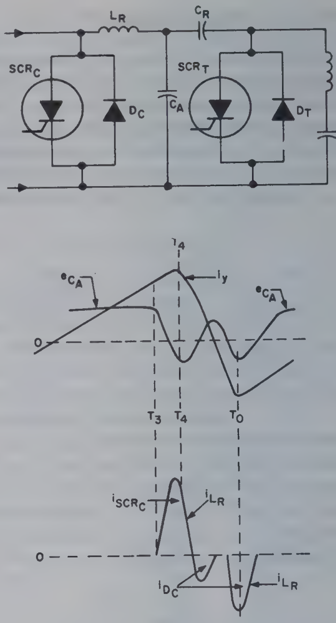


Fig. 12 — Circuit configuration showing the addition of auxiliary capacitor C_A and current and voltage waveforms showing the effect of this capacitor.

HIGH-VOLTAGE GENERATION

The SCR horizontal-deflection system in the RCA CTC-40 receiver generates the high voltage for the picture tube in essentially the same manner as has been used for many years in other commercial television receivers, i.e., by transformation of the horizontal-deflection retrace (flyback) pulse to a high voltage with a voltage step-up transformer and subsequent rectification of this stepped-up voltage. The RCA-3CZ3 electron tube is used as the high-voltage rectifier in the RCA CTC-40 television receiver.

Fig. 13 shows a schematic of the over-all high-voltage circuit, and Fig. 14 shows a simplified schematic of this circuit together with the significant voltage and current waveforms. The high-voltage transformer is connected across the yoke and retrace capacitor. The inductance and capacitance of this transformer are such that it presents a load tuned to about the third harmonic of the retrace resonant frequency. The presence of this load adds harmonic components to the waveforms previously described.

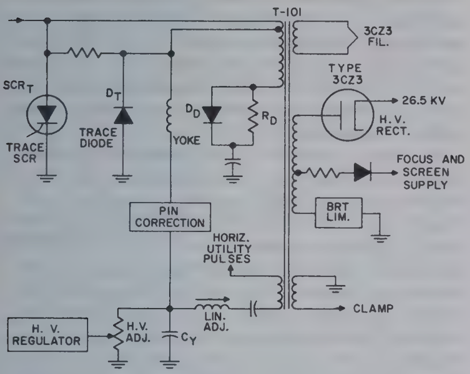


Fig. 13 — High-voltage circuit.

HIGH-VOLTAGE REGULATION

The high voltage is regulated by controlling the amount of energy made available to the horizontal-output trace circuit. As stated previously, the trace circuit is supplied by energy which is stored primarily on the commutating capacitor C_R. This capacitor is charged during the trace interval through inductance L_{CC}.

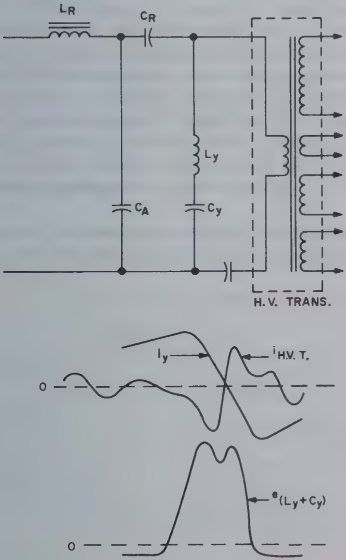


Fig. 14 — Simplified schematic and significant voltage and current waveforms for the high-voltage circuit.

Control of the high-voltage energy on the commutating capacitor is made possible by the design of inductor L_{CC} so that it approaches resonance with capacitor C_R; the degree of this resonance can be varied by the high-voltage regulator circuit.

Fig. 15 illustrates the effect of this resonant action on the charge on the commutating capacitor. The waveshape that results from the resonant action determines the amount of charge that will be on the capacitor when its energy is released into the trace circuit.

The resonance of the inductor L_{CC} and the commutating capacitor C_R is varied by use of a saturable reactor L_{SR} to control the inductance across L_{CC}. The saturable-reactor load winding is placed in parallel with L_{CC}. Changes in the current through the reactor control windings varies the total inductance of the input circuit. The current in the reactor load winding is controlled by the pulse regulator circuit.

The control current for the reactor control winding is determined by the conduction of the high-voltage regulator transistor Q_X. The collector current of this transistor is in turn controlled by the voltage across the yoke-return capacitor C_y. This voltage, which is directly proportional to high voltage and which tracks any changes in the high voltage, is sampled by the high-voltage adjustment control and compared to a reference voltage determined by a Zener diode. The resulting difference voltage, which is indicative of changes in the high voltage, controls the conduction of the regulator transistor.

As the high-voltage load (beam current) decreases, the high voltage tends to increase. The voltage across the yoke-return capacitor then tends to increase. This action results in an instantaneously higher current pulse through the base-emitter junction of the regulator transistor. The reactor control current, therefore, tends to increase proportionally, so that the total inductance of the input circuit is decreased. The resulting change in resonance of L_{CC}, L_{SR}, and C_R reduces the charge on C_R and the energy made available to the trace circuit. In this way, the high voltage is stabilized. The reverse action, of course, occurs if the high voltage tends to decrease.

Diode D_{ER} acts as an energy-recovery diode which improves the efficiency of the control circuit. The regulator transistor actually conducts only for a very short time, and the majority of the control current is supplied by diode conduction. This high-voltage regulating system also maintains the high voltage within acceptable limits for variations in the ac line voltage over the range from 105 to 130 volts.

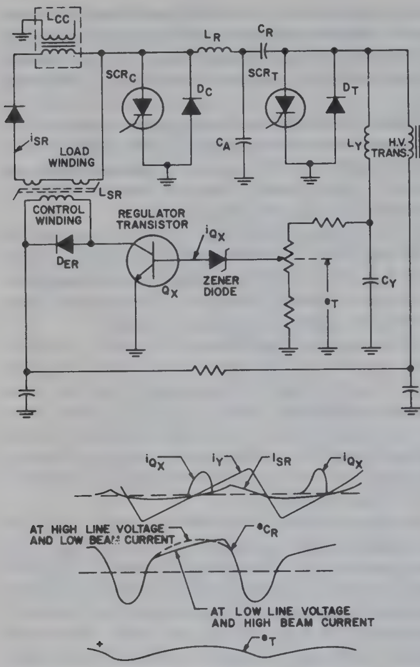

LCC
LR
CR
SCRC
DC
SCRT
DT
iSR
LOAD WINDING
CA
LY
H.V. TRANS.
LSR
CONTROL WINDING
REGULATOR TRANSISTOR
iQX
DER
QX
ZENER DIODE
eT
CY
iQX
iY
iSR
iQX
AT HIGH LINE VOLTAGE AND LOW BEAM CURRENT
eCR
AT LOW LINE VOLTAGE AND HIGH BEAM CURRENT
+
eT

Fig. 15 — High-voltage regulator and operating voltage and current waveforms.

ARC PROTECTION

Two circuits are included in the SCR deflection system to protect the trace-switch SCR and diode from high voltages and currents that may result because of arcing from the high-voltage rectifier or the picture tube. These circuits are shown in Fig. 16.

One circuit includes the parallel combination of a diode (D_D) and a 4.7-ohm resistor (R_D) connected in series with the primary of the high-voltage transformer. These components dampen the high ringing current that may occur as a result of high-voltage arcing. This current is mainly dissipated in the resistor R_D; The principal purpose of the shunting diode is to allow the normal initial flyback current to flow unimpeded so that the high voltage is not decreased by the dampening action of the resistor.

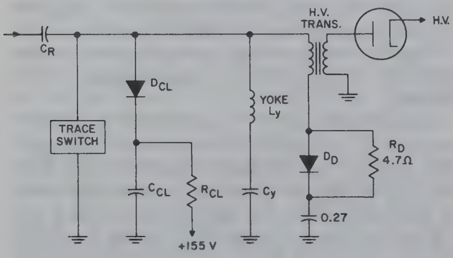

CR
H.V. TRANS.
H.V.
DCL
YOKE Ly
TRACE SWITCH
RD 4.7Ω
DD
CCL
RCL
Cy
0.27
+155 V

Fig. 16 — Arc-protection circuits.

The other protection circuit consists of a diode (D_{CL}), a capacitor (C_{CL}) connected between the diode cathode and ground, and a resistor R_{CL} from the diode cathode to the B+ supply voltage. The anode of the diode is connected to the ungrounded end of the primary of the high-voltage transformer. The diode conducts during the peak of the retrace voltage pulse that appears across the primary of the high-voltage transformer and charges the capacitor to this voltage. The resistor provides a high-resistance discharge path for the capacitor and allows the voltage across the capacitor to be reduced just enough to keep the diode reverse-biased during the retrace interval. When a sharp voltage pulse is produced because of high-voltage arcing, the diode conducts so that the trace switch is clamped to the voltage across the capacitor. The arc pulse voltage, therefore, is not allowed to exceed the breakdown voltage of the trace-switch components.

LINEARITY CORRECTION

Two means are provided in the SCR horizontal-deflection system to correct for nonlinearities in the horizontal scanning current that may result because of voltage drops across the inherent resistance in the trace circuit. Voltage drops across the resistance of the trace-switch SCR and diode are held to a minimum by operation of the trace diode at a more negative voltage than the trace SCR. This condition is achieved by connection of the trace diode one turn higher (more negative) on the high-voltage transformer than the SCR.

Fig. 17 illustrates another technique used to correct for nonlinearity in the scanning current. This technique

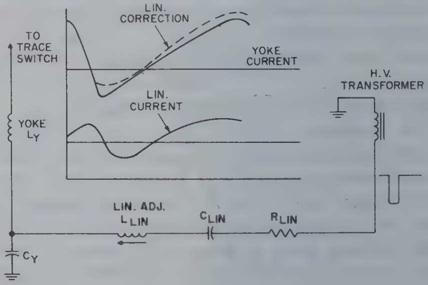

TO TRACE SWITCH
LIN. CORRECTION
YOKE CURRENT
H.V. TRANSFORMER
LIN. CURRENT
YOKE LY
LIN. ADJ. LLIN
CLIN
RLIN
CY

Fig. 17 — Linearity-correction circuit and correction-current waveforms.

uses a damped series resonant circuit (L_{LIN}, C_{LIN}, and R_{LIN}), connected between a winding on the high-voltage transformer and the ungrounded side of the yoke-return capacitor C_y, to produce a damped sine wave of current that effectively adds to and subtracts from the charge on the yoke-return capacitor C_y. The resulting alteration in yoke current corrects for any trace-current nonlinearities.

ADVANTAGES OF THE SCR HORIZONTAL-DEFLECTION SYSTEM

It is apparent from the preceding discussions that the SCR horizontal-deflection system offers a number of distinct advantages over the conventional types of systems currently used in commercial television receivers. The following list outlines some of the more significant circuit features of the SCR deflection system and points out the advantage derived from each of them:

1. Critical voltage and current waveforms, and timing cycles are determined by passive components in response to the action of two SCR-diode switches. The stability of the system, therefore, is determined primarily by the passive components. When the passive components are properly adjusted, the system exhibits highly predictable performance characteristics and exceptional operational dependability.
2. The only input drive signal required for the SCR deflection system is a low-power pulse which has no stringent accuracy specification in relation to either amplitude or time duration. The deflection system, therefore, can be driven directly from a pulse developed by the horizontal oscillator.
3. This deflection system is unique in that, although it operates from a conventional B+ supply of +155 volts, the flyback pulse is less than 500 volts. This level of voltage stress is substantially less than that in conventional line-operated systems, and this factor contributes to improved reliability of the switching devices.
4. Regulation in the SCR deflection system is accomplished by control of the energy stored by a reactive element. This technique avoids the use of resistive-load regulating elements required by many other types of systems and, therefore, makes possible higher over-all system efficiency and reduces input-power requirements.
5. All switching occurs at the zero current level through the reverse recovery of high-voltage p-n junctions in the deflection diodes. The diode junctions are not limited in volt-ampere switching capabilities for either normal or abnormal conditions in the circuit.

RCA
Solid State
Division

Thyristors
Application Note
AN-3822

Thermal Considerations in Mounting of RCA Thyristors

by

J. M. S. Neilson

Consideration of thermal problems involved in the mounting of thyristors is synonymous with consideration of the best heat sink for a particular application. Most practical heat sinks used in modern, compact equipment are the result of experiments with heat transfer through convection, radiation, and conduction in a given application. Although there are no set design formulas that provide exact heat-sink specifications for a given application, there are a number of simple rules that reduce the time required to evolve the best design for the job. These simple rules are as follows:

1. The surface area of the heat sink should be as large as possible to provide the greatest possible heat transfer. The area of the surface is dictated by thyristor case-temperature requirements and the environment in which the thyristor is to be placed.
2. The heat-sink surface should have an emissivity value near unity for optimum heat transfer by radiation. A value approaching unity can be obtained if the heat-sink surface is painted flat black.
3. The thermal conductivity of the heat-sink material should be such that excessive thermal gradients are not established across the heat sink.

Although these rules are followed in conventional heat-sink systems, the size and cost of such systems often become restrictive in compact, mass-produced power-control and power-switching applications using thyristors. These restrictions are overcome in RCA thyristors because the JEDEC TO-5 and "modified TO-5" packages shown in Figs.1 and 2 are tin-plated and can be soldered directly to a heat sink. The use of mass-produced prepunched parts, direct soldering, and batc soldering techniques eliminates many of the difficulti associated with heat sinks by making possible t use of a variety of simple, efficient, readily fabricat heat-sink configurations that can be easily incorporat into the mechanical design of equipment.

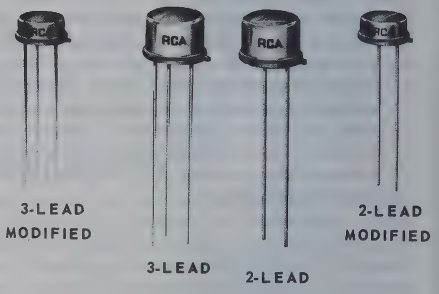
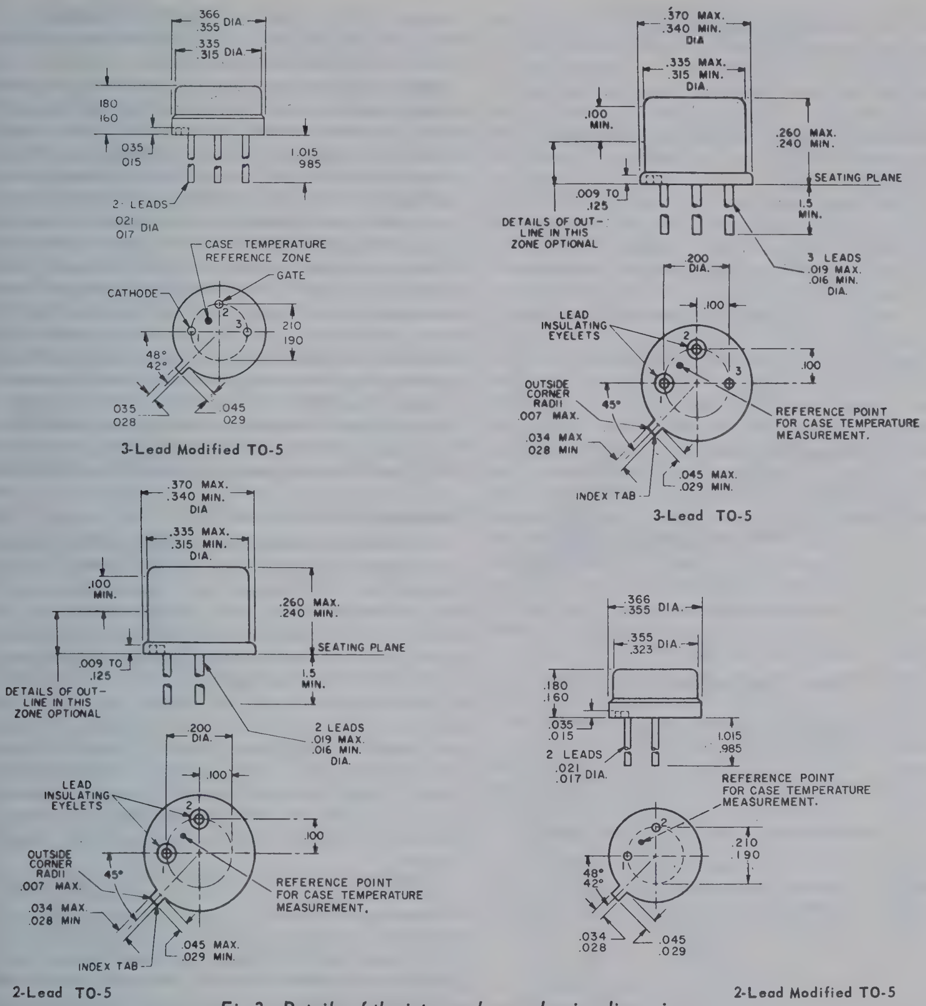


Fig.1 - RCA TO-5 thyristor packages.

Power Dissipation and Heat-Sink Area

The curves shown in Fig.3 are designed for use wi the power-dissipation curves shown in the technical bu letins describing the various RCA thyristors. The curv of Fig.3 are conservative and can be used directly f thyristors having thermal-resistance ratings (θ_r), jun tion-to-case, of 5°C/W or less. The curves shown Fig.4 represent the power-dissipation characteristics a typical thyristor. As an example of the use of Figs.3 a 4, it is assumed that an appropriate heat sink must b


366
355 DIA
335
315 DIA
180
160
035
015
1.015
985
2 LEADS
021
017 DIA
CASE TEMPERATURE REFERENCE ZONE
GATE
CATHODE
210
190
48°
42°
035
028
045
029
.370 MAX.
.340 MIN.
DIA
.335 MAX.
.315 MIN.
DIA.
.100 MIN.
.260 MAX.
.240 MIN.
SEATING PLANE
.009 TO .125
DETAILS OF OUTLINE IN THIS ZONE OPTIONAL
1.5 MIN.
3 LEADS .019 MAX. .016 MIN. DIA.
.200 DIA.
.100
LEAD INSULATING EYELETS
OUTSIDE CORNER RADII .007 MAX.
45°
.034 MAX
.028 MIN
.045 MAX.
.029 MIN.
INDEX TAB
REFERENCE POINT FOR CASE TEMPERATURE MEASUREMENT.
2 LEADS .019 MAX. .016 MIN. DIA.
.366
.355 DIA.
.355
.323 DIA.
.180
.160
.035
.015
1.015
.985
2 LEADS
.021
.017 DIA.
.210
.190
.034
.028
.045
.029

3-Lead Modified TO-5

3-Lead TO-5

2-Lead TO-5

2-Lead Modified TO-5

Fig.2 - Details of thyristor packages showing dimensions and reference point for case-temperature measurement.

found for a thyristor that is to conduct a current of 2 amperes, operate at an air temperature of 37°C, and be soldered to the heat sink at the base of the package. From Fig.4, the maximum power dissipation in the thyristor is found to be 3 watts. Fig.3 shows that the maximum allowable thermal resistance of the heat sink at this level of power dissipation is 15°C/W, and that a square, dull, 1/16-inch-thick copper or 1/8-inch-thick aluminum heat sink with an area of at least 1-3/4 by 1-1/4 inches is required.

The curves of Fig.3 can also be used with thyristors having junction-to-case thermal-resistance ratings of more than 5°C/W. However, the difference between the higher thermal-resistance value of the thyristor and the value of 5°C/W upon which the curves are based must be subtracted from the thermal-resistance values shown in Fig.3. For example, if it is assumed that the conditions are the same as those stated previously except that the thermal resistance, junction-to-case, of the device is 13°C/W, the difference in thermal-resistance

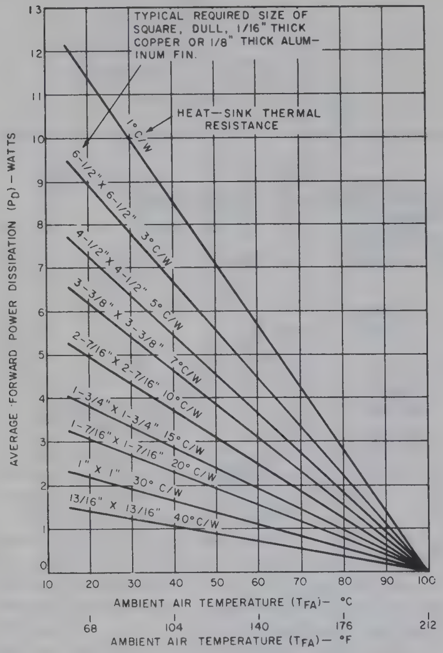


Fig.3 - Guide to heat-sink area determination.

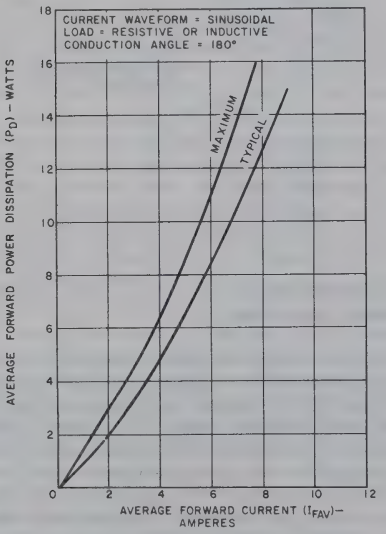


Fig.4 - Typical power-dissipation curves.

values is 8°C/W. The closest value of thermal resistance to 8°C/W in Fig.3 is 7°C/W; therefore, a 3-3/8-by-3-3/8-inch heat sink is required.

Commercial heat sinks are available for the thyristor packages described; however, because the thyristor package is usually attached to the heat sink at the cap, the additional thermal resistance from the base of the package to the cap must be considered. Although this resistance can be as high as 8°C/W, it can be neglected if it is only a small percentage of the over-all allowable thermal resistance. It should be noted that most thyristor thermal-resistance ratings are based on temperature measurements taken at the base of the package. The case-temperature reference point specified on the dimensional outlines shown in Fig.2 should be used when temperature measurements are made. A low-mass temperature probe or thermocouple equipped with wire leads no larger than AWG No. 26 should be employed for systems with thermal-resistance values less than 50°C/W. For systems with thermal-resistance values greater than 50°C/W, smaller wire (such as AWG No. 36) is preferred.

Mounting Thyristors on Heat Sinks

For most efficient heat sinks, intimate contact should exist between the heat sink and at least one-half of the package base. The package can be mounted on the heat sink mechanically, with glue or epoxy adhesive, or by soldering. If mechanical mounting is employed, silicone grease should be used between the device and the heat sink to eliminate surface voids, prevent insulation build-up due to oxidation, and help conduct heat across the interface. Although glue or epoxy adhesive provides good bonding, a significant amount of resistance may exist at the interface. To minimize this interface resistance, an adhesive material with low thermal resistance, such as Hysol* Epoxy Patch Material No. 6C or Wakefield* Delta Bond No. 152, or their equivalent, should be used.

Soldering of the thyristor to the heat sink is preferable because it is most efficient. Not only is the bond permanent, but interface resistance is easily kept below 1°C/W under normal soldering conditions. Oven or hot-plate batch-soldering techniques are recommended because of their low cost. The use of a self-jigging arrangement of the thyristor and the heat sink and a 60-40 solder preform is recommended. If each unit is soldered individually with a flame or electric soldering iron, the heat source should be held on the heat sink and the solder on the unit. Heat should be applied only long enough to permit solder to flow freely. Because RCA thyristors are tin-plated, maximum solder wetting is easily obtainable without thyristor overheating.

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* Products of Hysol Corporation, Olean, New York and Wakefield Engineering, Inc., Wakefield, Massachusetts, respectively.

The special high-conductivity leads on the two-lead TO-5 package permit operation of the thyristor at current levels that would be considered excessive for an ordinary TO-5 package. The special leads can be bent into almost any configuration to fit any mounting requirement; however, they are not intended to take repeated bending and unbending. In particular, repeated bending at the glass should be avoided. The leads are not especially brittle at this point, but the glass has a sharp edge which produces an excessively small radius of curvature in a bend made at the glass. Repeated bending with a small radius of curvature at a fixed point will cause fatigue and breakage in almost any material. For his reason, right-angle bends should be made at least 0.020 inch from the glass. This practice will avoid sharp bends and maintain sufficient electrical isolation between lead connections and header. A safe bend can be assured if the lead is gripped with pliers close to he glass seal and then bent the requisite amount with he fingers, as shown in Fig.5. When the leads of a number of devices are to be bent into a particular configuraion, it may be advantageous to use a lead-bending fixure to assure that all leads are bent to the same shape and in the correct place the first time, so that there is no need for repeated bending.

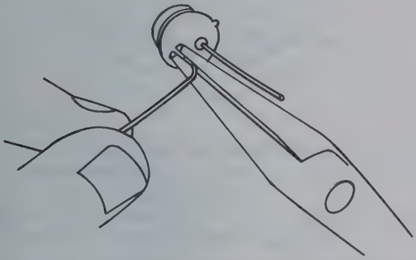

Fig.5 - Method of bending leads on thyristor package.

ypical Heat-Sink Configurations

Typical heat-sink designs that can be used with RCA hyristors are shown in Fig.6. The case-to-air thermal-esistance value for each of the easily fabricated sinks s given, along with approximate dimensions. The thystors in the illustrations are soldered to the heat sink; f epoxy is used, an additional thermal resistance of $^{\circ}$C/W to 2°C/W must be added to the thermal-resistance alues shown. The junction-to-case thermal-resistance alue for the particular thyristor being used should be dded to the values shown to obtain the over-all juncon-to-air thermal resistance of each configuration. In ie designs shown, electrical insulation of the heat sink om the chassis or equipment housing may be required.

hassis-Mounted Heat Sinks

In many applications, it is desirable and practical to use the chassis or equipment housing as the heat sink. In such cases, the thyristor must be electrically insulated from the heat sink, but must still permit heat generated by the device to be efficiently transferred to the chassis or housing. This heat transfer can be achieved by use of the heat-spreader mounting method. In this method, the thyristor is attached to a metal bracket (heat spreader) which is attached to, but electrically insulated from, the chassis. Examples of heat spreaders are shown in Figs.6 and 7. Electrical insulation may consist of material such as alumina ceramic, polyimide film or tape, fiberglass tape, or epoxy. The metal bracket itself has a low thermal resistance, and spreads the heat out over a larger area than could the thyristor case alone. The larger area in contact with the electrical insulation allows heat to transfer from bracket to chassis through the insulation with relatively low thermal resistance. Typical heat sinks, such as those shown in Fig.6, provide a much lower thermal resistance when used as heat spreaders than when used as heat sinks. Heat spreader dimensions can be varied over a wide range to suit particular applications. For example, area or diameter can be increased, or shape changed, as long as the heat-transfer area in contact with the electrical insulation is sufficient. An area of 0.2 square inch or more is usually desirable. The exact thermal resistance of any heat spreader depends on the heat-transfer area, type of metal used, type of insulation used, and whether the thyristor is fastened to the heat spreader with solder or epoxy. Soldered construction yields a thermal resistance about 1°C/W less than that obtained with epoxy. Alumina or polyimide insulation provides a thermal resistance about 1 to 2°C/W less than that obtained with thermosetting fiberglass-tape insulation. The heat spreader can be made of any material with suitable thermal conductivity, such as copper, brass, or aluminum. Solderable plating for aluminum is commercially available.

A self-jigging type of copper heat spreader is shown in Fig.7. SCR's soldered to this heat spreader are available from RCA as type numbers S2620B, S2620D, and S2620M.

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Frank D. Gross, "Semiconductor Heat-Sink Design Chart," *Electronics World,* January, 1965.

A. D. Marquis, "How 'Hot' Are You On Thermal Ratings?," *Electronic Design,* November 8, 1967.

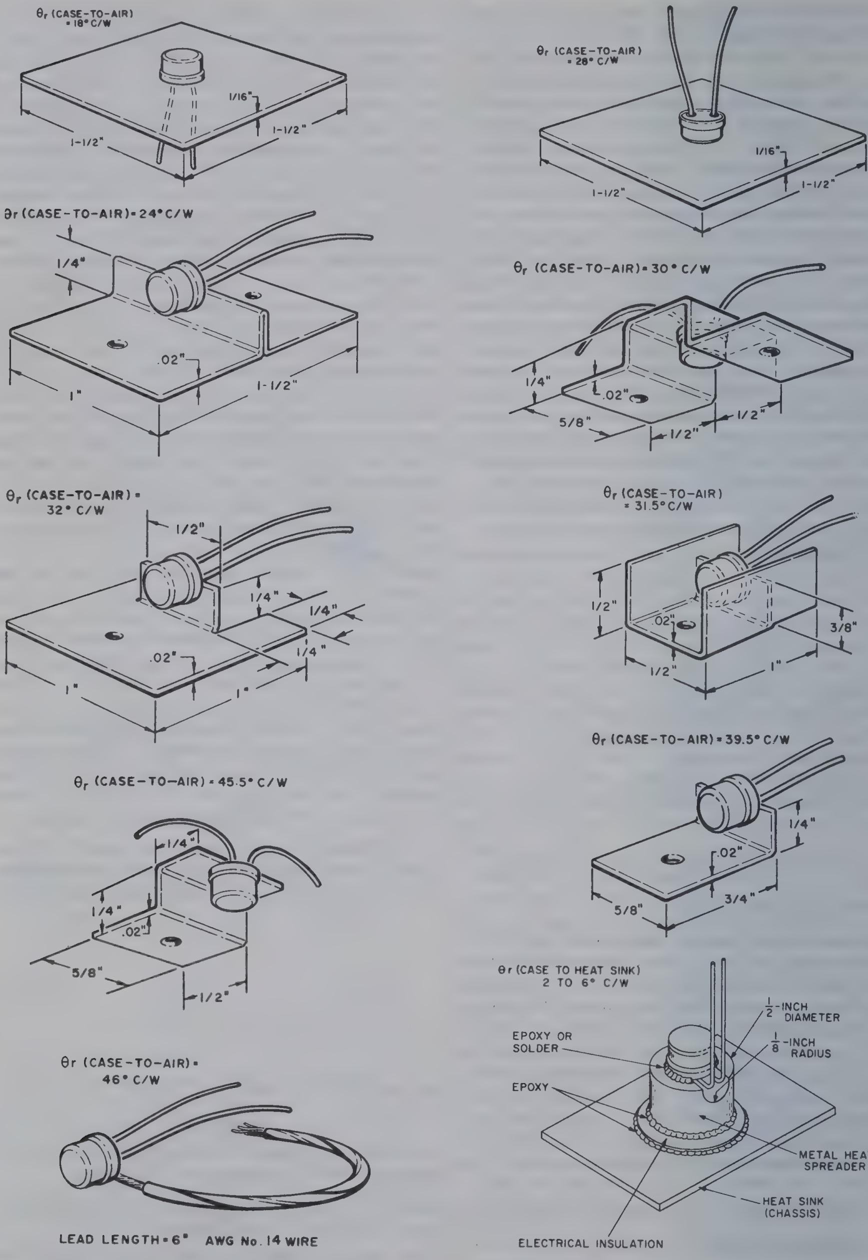

θr (CASE-TO-AIR) = 18° C/W
1/16"
1-1/2"
1-1/2"
θr (CASE-TO-AIR) = 28° C/W
1/16"
1-1/2"
1-1/2"
θr (CASE-TO-AIR) = 24° C/W
1/4"
.02"
1"
1-1/2"
θr (CASE-TO-AIR) = 30° C/W
1/4"
.02"
5/8"
1/2"
1/2"
θr (CASE-TO-AIR) = 32° C/W
1/2"
1/4"
1/4"
1/4"
.02"
1"
1"
θr (CASE-TO-AIR) = 31.5° C/W
1/2"
.02"
3/8"
1/2"
1"
θr (CASE-TO-AIR) = 39.5° C/W
1/4"
.02"
5/8"
3/4"
θr (CASE-TO-AIR) = 45.5° C/W
1/4"
1/4"
.02"
5/8"
1/2"
θr (CASE TO HEAT SINK) 2 TO 6° C/W
1/2-INCH DIAMETER
1/8-INCH RADIUS
EPOXY OR SOLDER
EPOXY
METAL HEAT SPREADER
HEAT SINK (CHASSIS)
ELECTRICAL INSULATION
θr (CASE-TO-AIR) = 46° C/W
LEAD LENGTH = 6" AWG No. 14 WIRE

Fig.6 - Typical heat-sink heat-spreader configurations.

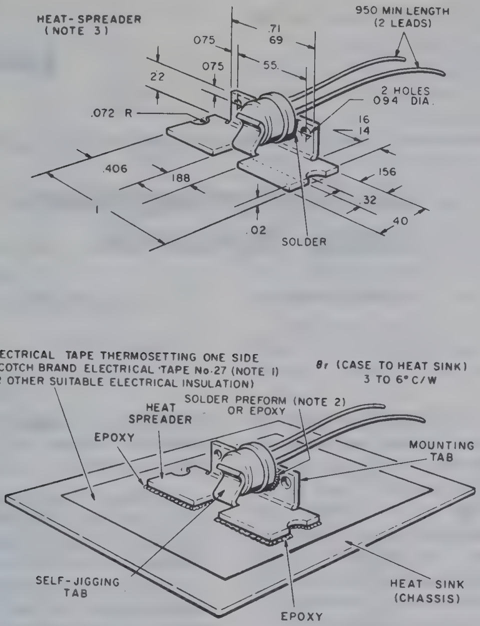

HEAT-SPREADER (NOTE 3)
950 MIN LENGTH (2 LEADS)
.71
.69
.075
.075
.55
.22
.072 R
2 HOLES .094 DIA.
.16
.14
.406
.188
.156
.32
.40
1
.02
SOLDER
ELECTRICAL TAPE THERMOSETTING ONE SIDE (SCOTCH BRAND ELECTRICAL TAPE No.27 (NOTE 1) OR OTHER SUITABLE ELECTRICAL INSULATION)
θr (CASE TO HEAT SINK) 3 TO 6°C/W
SOLDER PREFORM (NOTE 2) OR EPOXY
HEAT SPREADER
EPOXY
MOUNTING TAB
SELF-JIGGING TAB
HEAT SINK (CHASSIS)
EPOXY

Fig.7 - Self-jigging heat spreader.

NOTES:

1. Products of Minnesota Mining & Mfg. Co., St. Paul, Minnesota.
2. Solder preforms are available from RCA as Part No.NR184A and from the Kester Solder Co., Newark, N.J. 07105 as Part No.KSFD-375005.
3. This heat spreader is available from RCA as Part No.NR166B and from the General Stamping Co., Inc. Denville, N.J. 07834 as Part No.14-110.

RCA
Solid State
Division

Thyristors
Application Note
AN-3886

AC Voltage Regulators Using Thyristors

by G. J. Granieri

This Note describes a basic ac-voltage regulating technique using thyristors that prevents ac rms or dc voltage from fluctuating more than ± 3 per cent in spite of wide variations in input line voltage. Load voltage can also be held within ± 3 per cent of a desired value despite variations in load impedance through the use of a voltage-feedback technique. The voltage regulator described can be used in photocopying machines, light dimmers, dc power supplies, and motor controllers (to maintain fixed speed under fixed load conditions).

Circuit Operation

The schematic diagram of the ac regulator is shown in Fig.1. For simplicity, only a half-wave SCR configuration is shown; however, the explanation of circuit operation is easily extended to include a full-wave regulator that uses a triac.

The trigger device Q_1 used in Fig.1, a diac such as the RCA-D3202U, is an all-diffused three-layer trigger diode. This diac exhibits a high-impedance, low-leakage-current characteristic until the applied voltage reaches the breakover voltage V_{BO}, approximately 35 volts. Above this voltage, the device exhibits a negative resistance so that voltage decreases as current increases.

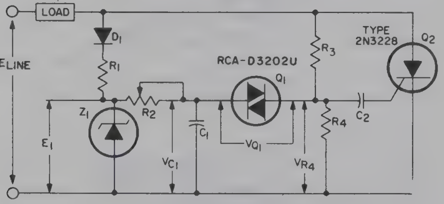


Fig.1 - A basic ac regulator.

Capacitor C_1 in Fig.1 is charged from a constant-voltage source established by zener diode Z_1. The capacitor is charged, therefore, at an exponential rate regardless of line-voltage fluctuations. A trigger pulse is delivered to the 2N3228 SCR, Q_2, when the voltage across capacitor C_1 is equal to the trigger voltage of diac Q_1 plus the instantaneous voltage drop developed across R_4 during the positive half-cycle of line voltage. When Q_1 is turned on, Q_2 is turned on for the remainder of the positive cycle of source voltage. Control of the conduction angle of the SCR regulates rms voltage to the load.

Regulation is achieved by the following means: When line voltage increases, the voltage across R_4 increases, but the charging rate of C_1 remains the same; as a result, the voltage across C_1 must attain a larger value than required without line-voltage increase before diac Q_1 can be triggered. The net effect is that the pulse that triggers Q_2 is delayed and the rms voltage to the load is reduced. In a similar manner, as line voltage is reduced, Q_2 turns on earlier in the cycle and increases the effective voltage across the load.

Fig.2 shows the voltage waveforms exhibited by the ac regulator at both high and low line voltage. The charging voltage for capacitor C_1, E_1, is equal to the zener voltage and remains constant up to the instant that the SCR is turned on. The capacitor voltage, V_{C1}, increases exponentially because the charging voltage E_1 is constant. The voltage across resistor R_4 conforms

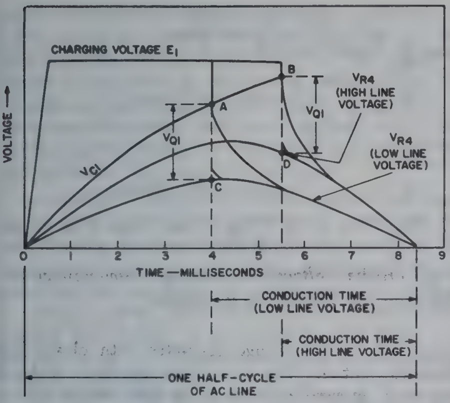


Fig.2 - Voltage waveforms exhibited by the ac regulator in Fig.1.

to the sinusoidal variations of the 60-Hz line voltage. At any given phase angle, the voltage across R_4 increases if line voltage increases and decreases if line voltage decreases.

The diac and SCR both trigger when the capacitor voltage, V_{C1}, equals the breakdown voltage of the diac plus the instantaneous value of voltage developed across R_4 during the positive half-cycle of line voltage. This capacitor voltage is represented by points A and B for the low and high line-voltage conditions, respectively. The instantaneous voltages across R_4 just before the SCR is triggered are represented by points C and D for the low and high line-voltage conditions, respectively. The voltage difference between points A and C and between points B and D is equal to the breakdown voltage of the diac.

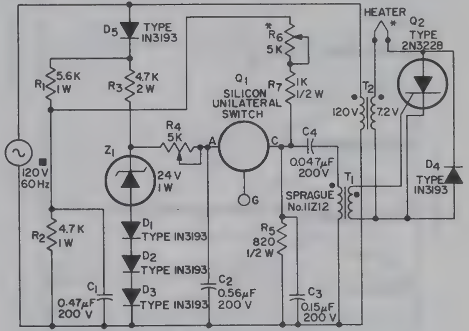
Fig.2 illustrates that the conduction time of the SCR is decreased as line voltage increases, and is increased when the line voltage decreases. By proper selection of the values of the voltage-divider-ratio resistors R_3 and R_4, it is possible to prevent the load voltage from varying more than 3 per cent with a 30-per-cent (approximate) change in line voltage.

It should be mentioned that during measurements of load voltage careful consideration must be given to the measuring instruments. Most of the circuits described in this Note produce a non-sinusoidal voltage across the load; the rms value of this voltage can be measured only with a true rms meter, such as a thermocouple meter. It is possible, however, that in certain applications the low input impedance of the thermocouple meter might load down the circuit being measured. In such cases, a high-input-impedance rms meter may be required.

HEATER REGULATION

Fig.3 shows a basic regulating technique for applications in which it is desired to maintain constant voltage across a load such as a receiving-tube heater, the filament of an incandescent lamp, or possibly a space heater. It should be noted that this configuration is actually a half-wave regulator. However, the circuit of Fig.3 differs from the circuit of Fig.1, in which one half-cycle is blocked from the load and the other half-cycle is phase-controlled to provide regulation. In Fig.3, essentially full voltage is applied to the load for one half-cycle by means of D4; the other half-cycle is phase-controlled by the SCR to provide regulation.

The circuit in Fig.3 is an open-loop regulator that features a high degree of safety; i.e., an open– or short-circuited component does not result in an excessive load voltage. Phase-controlled voltage regulation is provided by a silicon unilateral switch Q1* and a control circuit, as follows: Capacitor C_2 is charged from a voltage source that is maintained constant by zener diode Z_1; diodes D_1, D_2, and D_3 compensate for the change in zener voltage with temperature. The voltage across C_2 increases until the sum of the breakover voltage of Q_1 and the instantaneous voltage across R_5 is exceeded. At this point, a positive pulse is coupled into the gate of Q_2 by means of the pulse transformer T_1. The SCR Q_2 then switches on for the remainder of the positive cycle of line voltage. Control of the conduction angle of the SCR varies rms voltage to the heater.



*In the closed-loop regulator, R_6 is replaced by a photocell, and a potentiometer in series with a 6-volt incandescent lamp is connected in parallel with the heater terminals

Note: All resistor values are in ohms

▪For 220-V, 50/60-Hz Operation: R1=R2=10 K, 2 W; R3=10 K, 4 W; T2=220 V/7.2 V.

Fig.3 - A circuit using a regulator to maintain voltage constant across a load.

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* A silicon unilateral switch is a silicon, planar, monolithic integrated circuit that has thyristor electrical characteristics closely approximating those of an ideal four-layer diode. The device shown switches at approximately 8 volts.

As line voltage increases, the voltage across R_5 also increases; because C_2 charges along the same exponential curve, however, the voltage across C_2 must attain a larger value before Q_2 is turned on. The net effect is a delay in the trigger pulse and reduced rms voltage across the heater. In a similar manner, as line voltage is reduced, the SCR turns on earlier in the cycle and increases the effective voltage across the heater. By proper adjustment of potentiometer R_6 in conjunction with potentiometer R_4, it is possible to obtain excellent heater-voltage compensation over a range of line voltages. Fig.4 shows the waveforms associated with the heater-regulator circuit.

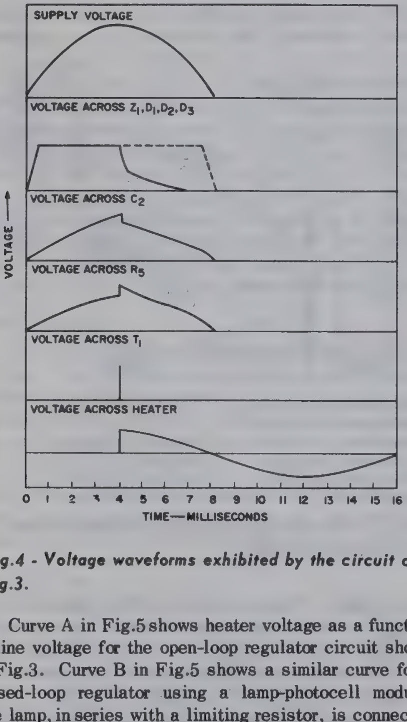


Fig.4 - Voltage waveforms exhibited by the circuit of Fig.3.

Curve A in Fig.5 shows heater voltage as a function of line voltage for the open-loop regulator circuit shown in Fig.3. Curve B in Fig.5 shows a similar curve for a closed-loop regulator using a lamp-photocell module. The lamp, in series with a limiting resistor, is connected across the heater terminals, and the photocell replaces R_6. The lamp unit senses the phase-controlled true rms heater voltage. Changes in lamp brightness produced by heater-voltage variations change the photocell resistance in reverse proportion to the lamp voltage. The remainder of the circuit functions as previously described except that regulation is obtained not only through the monitoring of the instantaneous magnitude of line voltage, but also through the sensing of the true rms voltage across the heater. This characteristic identifies the circuit as an ac voltage regulator with closed-loop feedback control. The closed-loop regulator produces less error, is more resistant to the drift effects of components, and is easier to adjust than the open-loop regulator.

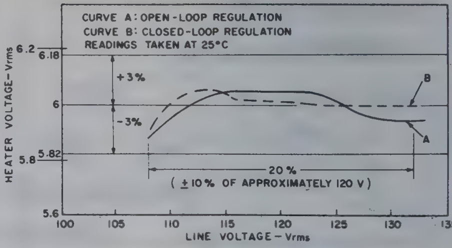


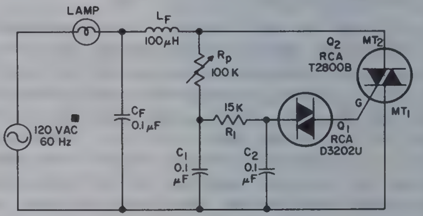
Fig.5 - Heater voltage as a function of line voltage of the open- and closed-loop regulators.

The lamp used in the closed-loop regulator is rated at 6 volts, but the series resistor limits the voltage to approximately 2 volts so that extremely long lamp life can be expected. An additional advantage at low voltage is that the light intensity varies linearly with the voltage across the lamp so that a small increase in voltage increases brightness markedly; near rated voltage the intensity does not vary linearly and the variation in brightness is not very apparent. A loss in sensitivity would result if the lamp were operated at its rated voltage.

The open-loop regulator can regulate 6 volts to within ± 3 per cent within a temperature range from 10 to 40°C with an input-voltage swing of ± 10 per cent. The closed-loop regulator can regulate 6 volts to within ± 2 per cent within a temperature range from 0 to 60°C with an input-voltage swing of ± 10 per cent.

LIGHT DIMMER WITH OVER-VOLTAGE CLAMP

Light-dimmer circuits are becomingly increasingly popular for home use. Fig.6 shows a typical light-dimmer configuration. This circuit provides the advantages of low hysteresis and continuous control up to the maximum conduction angle. At low illumination



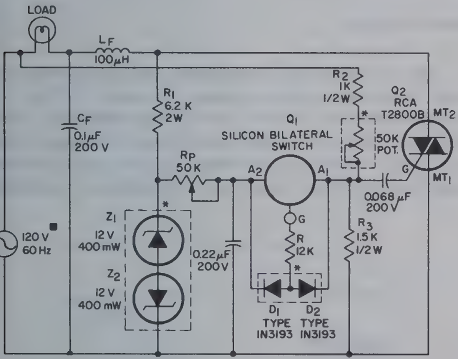
■ For 220-V, 50/60-Hz Operation, replace T2800B with T2800D.

Fig.6 - A typical light-dimmer circuit.

levels, however, the variable resistor R_p is adjusted to a high resistance setting. If a momentary drop in line voltage occurs at this condition, the high breakover voltage of the diac in conjunction with the high resistance could result in a circuit misfire; i.e., the light could be extinguished and remain so until the circuit is reset by readjustment of the control to a high illumination setting.

A natural successor to the circuit of Fig.6 might consist of a configuration which not only provides the light-dimming function but also extends the life of the lamp being controlled. One of the major causes of reduced lamp life can be directly attributed to line-voltage fluctuations and in particular to periods of over-voltage. Nominal line voltage is approximately 120 volts ± 10 per cent; it is the + 10-per-cent variation that causes lamps to reach end-of-life prematurely.

A technique for limiting or clamping the lamp voltage, without sacrificing any of the desirable features of the dimmer of Fig.6, is shown in Fig.7; L_F and C_F suppress rf interference. Fig.7 employs the basic regulating circuit described earlier; however, in the configuration shown, the switching voltage of Q_1, a silicon bilateral switch,* is reduced by steering diodes D_1 and D_2 in conjunction with resistor R. This arrangement not only makes it possible to achieve larger conduction angles, but also prevents the circuit from misfiring at low illumination levels when it is subjected to dips in line voltage. The light-dimmer circuit in Fig.7 is capable of clamping the high-line-voltage condition to within +3 per cent of its nominal value; as a result, the lamp is subjected to voltages of 120 volts plus 3 per cent and minus 10 per cent. The −10-per-cent line dip has little effect on lamp-life reduction.



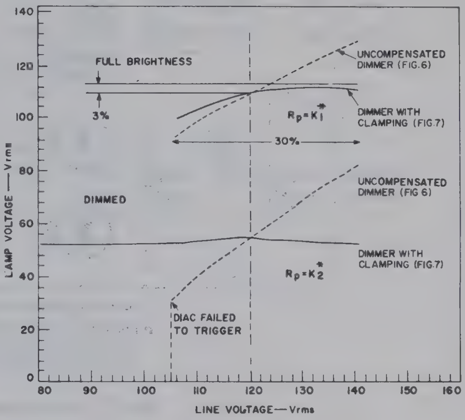
*DASHED LINES INDICATE MAJOR ADDITIONAL COMPONENTS REQUIRED TO ACHIEVE VOLTAGE CLAMP

NOTE: ALL RESISTOR VALUES ARE IN OHMS

■ For 220-V, 50/60-Hz OPERATION:
C_F=0.1 µF,400 V; R1=12 K,4 W;
R2=2 K,4 W; R3=3 K,4 W; Q2=T2800D

Fig.7 - A light-dimmer circuit that includes clamping.

The circuit also regulates lamp voltage for various settings of potentiometer R_p. Fig.8 shows line voltage as a function of lamp voltage for two settings of R_p for the circuits of Figs.6 and 7. These curves illustrate the increased regulation achieved by the improved circuit.



*K_1 AND K_2 ARE ARBITRARY BUT DIFFERENT VALUES

Fig.8 - Lamp voltage as a function of line voltage for two values of R_p in the circuits of Figs.6 and 7.

The dimmer configuration of Fig.7 can also be used as a 120-volt full-wave heater regulator. In this application the light is replaced by a heater load. If the load can be operated at a nominal 100 volts with an input voltage of 120 volts, more symmetrical regulation can be realized; i.e., ±3 per cent regulation can be achieved with a line variation of ±10 per cent. In the full-wave heater-regulator application, diodes D_1, D_2, and resistor R in Fig.7 can be eliminated because a wide conduction angle is not required.

Such a control might also be used in colorimetry, an application in which it is necessary to match the color (and temperature) of a lamp with a standard; in this application line-voltage fluctuations can create a measurement error. Other areas of application, such as photography, heater control, and hot-plate and solder-pot control, can also make effective use of the dimmer circuit with over-voltage clamp.

VOLTAGE-REGULATED DC SUPPLY

A simple but stable dc power supply using thyristors is shown in Fig.9. The power-supply section consists of the well known full-wave bridge with RC filter.

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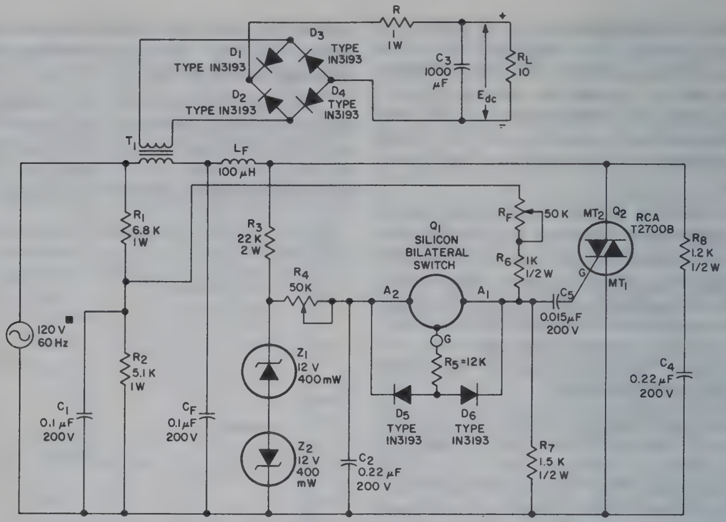
* A silicon bilateral switch is a silicon, planar, monolithic integrated circuit that switches at approximately 8 volts in both directions.


R
1
1W
D3
D1
TYPE IN3193
TYPE
IN3193
C3
1000
μF
RL
10
+
Edc
−
D2
TYPE IN3193
D4
TYPE
IN3193
T1
LF
100 μH
R1
6.8 K
1W
R3
22 K
2 W
RF
50 K
MT2
Q2
RCA
T2700B
Q1
SILICON
BILATERAL
SWITCH
R6
1K
1/2 W
R8
1.2 K
1/2 W
R4
50K
A2
A1
G
MT1
C5
0.015μF
200 V
120 V
60 Hz
G
R5=12K
Z1
12 V
400mW
R2
5.1 K
1W
C4
0.22 μF
200 V
C1
0.1 μF
200V
CF
0.1μF
200V
D5
TYPE
IN3193
D6
TYPE
IN3193
Z2
12 V
400
mW
C2
0.22 μF
200 V
R7
1.5 K
1/2 W

NOTE: ALL RESISTOR VALUES ARE IN OHMS

■ For 220-V, 50/60-Hz Operation:
R1=12 K,2 W; R2=10 K,2 W; R3=47 K,
4 W; C4=0.22 μF,400 V; Q2=T2700D

Fig.9 - A voltage-regulated dc supply.

A line-voltage transformer is employed to step-down the supply voltage of 120 volts rms to approximately 12.5 volts rms. If a dc output voltage greater than 10 volts is desired, a transformer with a lower primary-to-secondary turns ratio should be employed.

The heart of the regulator shown in Fig.9 is the phase-controlled triac on the primary side of the line transformer. Because the load presented to the triac is somewhat inductive, an RC network is used to assure proper commutation; L_F and C_F suppress rf interference. The circuit automatically compensates for wide variations in line voltage. Fig.10 shows a curve of line voltage as a function of load voltage, E_{dc}, for a constant load of 10 ohms. Fig.11 shows the voltage waveforms associated with the circuit of Fig.9.

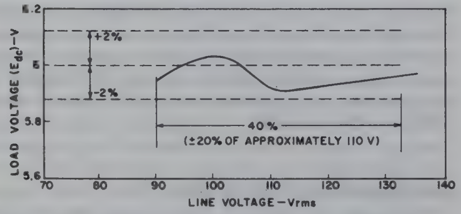


Fig.10 - Load voltage as a function of line voltage for the circuit of Fig.9; load resistance is constant at 10 ohms.

If increased line, temperature, and load conpensa-tion is desired in the regulated dc supply of Fig.9, closed-loop type of control can be obtained by use of photocell in place of R_F and connection of a lamp acros the output terminals of the supply in such a way that the light from the lamp can impinge on the photocell surface.

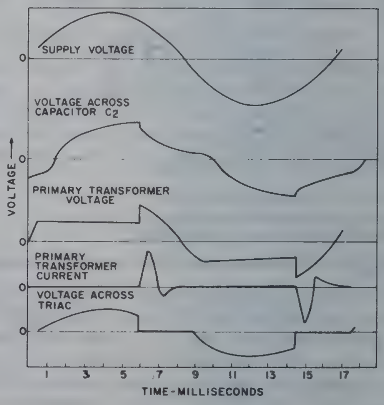


Fig.11 - Voltage waveforms exhibited by the circuit o Fig.9.

SELECTION OF CONTROL DEVICE

Other thyristors than those shown in this Note can also be used for voltage regulation. The selection of an SCR or triac for a particular regulating circuit depends on the voltage and current requirements of the application. The quick-selection charts shown below indicate the capabilities of RCA thyristors for this type of usage.

Triac Quick-Selection Chart

	0.35A	6A	10A	15A	30A	40A
120-Volt Line Operation	T2300B	T2700B	2N5567	2N5571	T6401B	2N5441
	T2302B	T2710B	2N5569	2N5573	T6411B	2N5444
	T2310B			T4700B		
	T2312B					
240-Volt Line Operation	T2300D	T2700D	2N5568	2N5572	T6401D	2N5442
	T2302D	T2710D	2N5570	2N5574	T6411D	2N5445
	T2310D			T4700D		
	T2312D					

SCR Quick-Selection Chart

	2A	5A	12.5A	15A	25A	35A
120-Volt Line Operation	2N3528	2N3228	2N3669	2N1846A	1N685	2N3871
		S2710B				2N3897
		S3700B				
240-Volt Line Operation	2N3529	2N3525	2N3670	2N1849A	2N688	2N3872
		S2710D				2N3898
		S3700D				

RCA
Solid State Division

Power Transistors and Thyristors

Application Note AN-4124

Handling and Mounting of RCA Molded-Plastic Transistors and Thyristors

by W.J. Hepp, J.S. Vara, and J. Gaylord

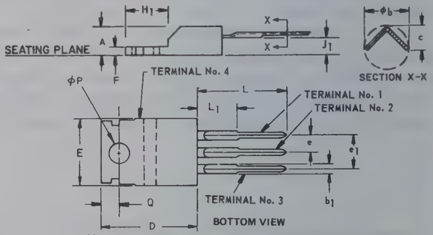
RCA power transistors and thyristors (SCR's and triacs) in molded-silicone-plastic packages are available in a wide range of power-dissipation ratings and a variety of package configurations. This Note provides detailed guidelines for handling and mounting of these plastic-package devices, and shows different types of packages and suggested mounting hardware to accommodate various mounting arrangements. Recommendations are made for handling of the packages during the forming of leads to meet specific mounting requirements. Various mounting arrangements, thermal considerations, and cleaning methods are described. This information is intended to augment the data on electrical characteristics, safe operating area, and performance capabilities in the technical bulletin for each type of plastic-package transistor or thyristor. (Data on mechanical and environmental capabilities of RCA plastic-package transistors are also available in a periodically updated **Reliability Report**, RCA Publication No. HBT-600.)

TYPES OF PACKAGES

Two basic types of molded-plastic packages are used for RCA solid-state power devices. These types include the RCA Versawatt packages for medium-power applications and the RCA high-power plastic packages, both of which are specifically designed for ease of use in many applications. Each basic type offers several different package options, and the user can select the configuration best suited to his particular application.

Figs. 1 through 3 show the options currently available for devices in RCA Versawatt packages. The JEDEC Type TO-220AB in-line-lead version, shown in Fig. 1, represents the basic style. This configuration features leads that can be formed to meet a variety of specific mounting requirements. Fig. 2 shows a package configuration that allows a Versawatt package to be mounted on a printed-circuit board with a 0.100-inch grid and a minimum lead spacing of 0.200 inch. Fig. 3 shows a JEDEC Type TO-220AA version of the Versawatt package. The dimensions of this type of transistor package are such that it can replace the JEDEC TO-66 transistor package in a commercial socket or printed-circuit board without retooling. The pin-connection arrangement of thyristors supplied in TO-220AA packages, however, differs from that of thyristors supplied in conventional TO-66 packages so that some hardware changes are required to effect a replacement. The TO-220AA Versawatt package is also supplied with an integral heat sink. Fig. 4 shows the dimensional outline for this heat sink. The use of the integral heat sink reduces the junction-to-air thermal resistance of the package from 70°C per watt to 35°C per watt.

The RCA molded-plastic high-power packages are also supplied in several configurations for flexibility of application. The JEDEC Type TO-219AB, shown in Fig. 5, is the basic high-power plastic package. Fig. 6 shows a JEDEC Type TO-219AA version of the high-power plastic package.



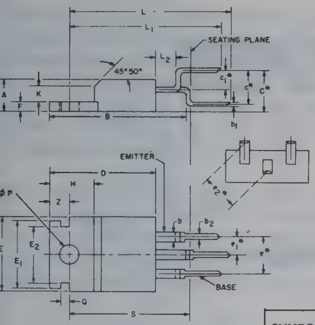
SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.140	0.190	3.56	4.82	–
φb	0.020	0.045	0.51	1.14	–
b_1	0.045	0.070	1.15	1.77	–
c	0.015	0.030	0.38	0.762	–
D	0.560	0.625	14.23	15.87	–
E	0.380	0.420	9.66	10.66	1
e	0.090	0.110	2.29	2.79	2
e_1	0.190	0.210	4.83	5.33	2
F	0.045	0.055	1.15	1.39	–
H_1	0.230	0.270	5.85	6.85	1
J_1	0.080	0.115	2.04	2.92	–
L	0.500	0.562	12.70	14.27	–
L_1	–	0.250	–	6.35	–
φP	0.139	0.147	3.531	3.733	–
Q	0.100	0.120	2.54	3.04	–

NOTES:

1. Tab contour optional within H_1 and E.
2. Position of lead to be measured 0.250 – 0.255 in. (6.35 – 6.48 mm) from case.

92CS-17991R1

Fig. 1 - Dimensional outline of the JEDEC TO-220AB in-line-lead Versawatt transistor package.


L
L1
SEATING PLANE
L2
45°50°
c1*
c*
C*
A
K
F
B
b1
EMITTER
D
H
ϕP
Z
e2*
b
b2
E2
E1
e1*
e*
BASE
Q
S

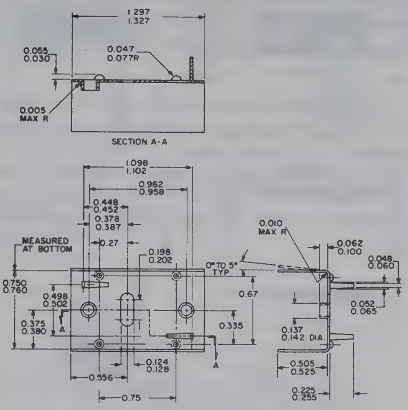
* MEASURED AT SEATING PLANE

92CS-17175

SYMBOL	INCHES		MILLIMETERS	
	MIN.	MAX.	MIN.	MAX.
e_2	0.203	0.243	5.16	6.17
F	0.045	0.055	1.15	1.39
H	0.230	0.270	5.85	6.85
K	0.080	0.085	2.032	2.159
L	0.993	1.033	25.22	26.23
L_1	0.895	0.935	22.73	23.74
L_2	0.070	0.090	1.78	2.28
ϕP	0.139	0.147	3.531	3.734
Q	0.040	0.060	1.02	1.52
S	0.655	0.685	16.64	17.39
Z	0.100	0.120	2.54	3.04

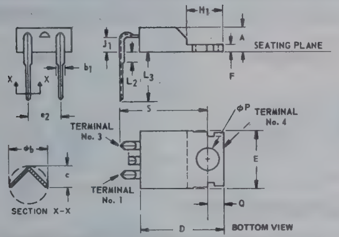
SYMBOL	INCHES		MILLIMETERS	
	MIN.	MAX.	MIN.	MAX.
A	0.140	0.190	3.56	4.82
B		0.850	–	21.59
b	0.045	0.070	1.15	1.17
b_1	0.015	0.030	0.382	0.762
b_2	0.020	0.038	0.508	0.965
C	0.230	0.270	5.85	6.85
c	0.180	0.220	4.58	5.58
c_1	0.130	0.170	3.31	4.31
D	0.560	0.625	14.23	15.87
E	0.380	0.420	9.66	10.41
E_1	0.365	0.385	9.28	9.77
E_2	0.300	0.320	7.62	8.12
e	0.190	0.210	4.83	5.33
e_1	0.090	0.110	2.29	2.79

Fig. 2 - Dimensional outline of Versawatt transistor package designed for mounting on printed-circuit boards.


1.297
1.327
0.055
0.030
0.047
0.077R
0.005
MAX R
SECTION A-A
1.098
1.102
0.962
0.958
0.448
0.452
0.378
0.387
MEASURED AT BOTTOM
0.27
0.198
0.202
0.010
MAX R
0.062
0.100
0.048
0.060
0° TO 5° TYP.
0.750
0.760
0.498
0.502
0.67
0.375
0.380
A
0.335
0.052
0.065
0.137
0.142 DIA.
0.124
0.128
A
0.556
0.505
0.525
0.75
0.225
0.255

ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SHOWN. TOLERANCES ARE: ±0.02 FOR 2ND PLACE; ±0.005 FOR 3RD PLACE AND ±1/2° FOR ANGULAR DIMENSION.

Fig. 4 - Integral heat sink used with the TO-220AA Versawatt package shown in Fig. 3.

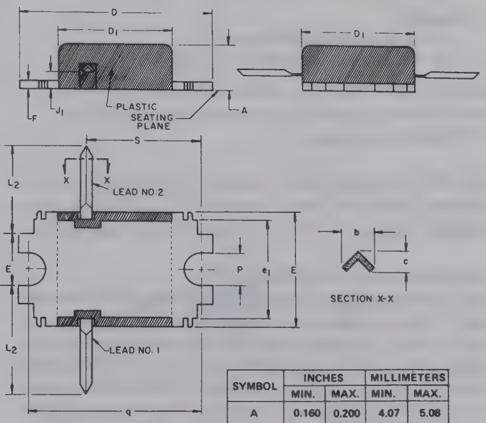

H1
J1
A
SEATING PLANE
X
X
b1
L2
L3
F
e2
S
ϕP
TERMINAL No. 4
TERMINAL No. 3
ϕb
c
E
TERMINAL No. 1
SECTION X-X
Q
D
BOTTOM VIEW

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.140	0.190	3.56	4.82	–
ϕb	0.02	0.045	0.51	1.14	–
b_1	0.045	0.070	1.15	1.77	–
c	0.015	0.030	0.38	0.762	–
D	0.560	0.625	14.23	15.87	–
E	0.380	0.420	9.66	10.66	1
e_2	0.190	0.210	4.83	5.33	2
F	0.045	0.055	1.15	1.39	–
H_1	0.230	0.270	5.85	6.85	1
J_1	0.080	0.115	2.04	2.92	–
L_2	–	0.050	–	1.27	–
L_3	0.360	0.422	9.15	10.71	–
ϕP	0.139	0.147	3.531	3.733	–
Q	0.100	0.120	2.54	3.04	–
S	0.580	0.610	14.74	15.49	–

92CS-17990R1

NOTES:
1. Tab contour optional within H_1 and E.
2. Position of lead to be measured 0.050 – 0.055 in. (1.27 – 1.40 mm) below seating plane.

ig. 3 - JEDEC TO-220AA Versawatt transistor package esigned for direct replacement of the JEDEC TO-66 ackage.

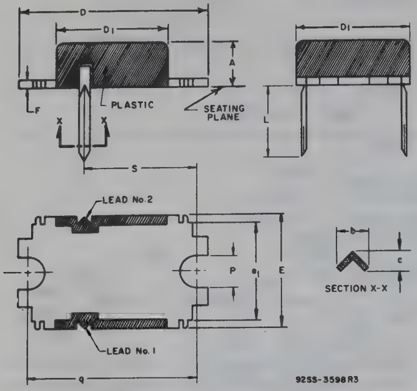

D
D1
D1
F
J1
PLASTIC
SEATING PLANE
A
S
L2
X
X
LEAD NO.2
E
P
e1
E
b
c
SECTION X-X
L2
LEAD NO. 1
q

SYMBOL	INCHES		MILLIMETERS	
	MIN.	MAX.	MIN.	MAX.
A	0.160	0.200	4.07	5.08
b	0.045	0.060	1.15	1.52
c	0.025	0.045	0.64	1.14
D	0.890	0.910	22.61	23.11
D_1	0.480	0.515	12.20	13.03
E	0.480	0.520	12.20	13.20
F	0.055	0.070	1.40	1.77
J_1	0.100	0.120	2.54	3.04
L_2	0.415	0.560	10.54	14.22
P	0.128	0.150	3.26	3.81
q	0.740	0.760	18.80	19.30
s	0.500	0.520	12.70	13.20

NOTE: Terminal end configurations are optional.

92SS-3599R2

Fig. 5 - JEDEC TO-219AB high-power molded-plastic transistor package.



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.160	0.200	4.07	5.08	
b	0.045	0.060	1.15	1.52	
c	0.025	0.045	0.64	1.14	
D	0.890	0.910	22.61	23.11	
D_1	0.480	0.515	12.20	13.08	
E	0.480	0.520	12.20	13.20	
e_1	0.460	0.505	11.69	12.82	1
F	0.055	0.070	1.40	1.77	
L	0.370	0.450	9.40	11.43	2
P	0.128	0.150	3.26	3.81	
q	0.740	0.760	18.80	19.30	
s	0.500	0.520	12.70	13.20	

NOTES:

1. **e_1 is measured at seating plane.**
2. **Terminal end configurations are optional.**

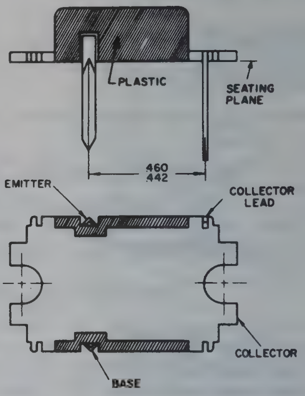
Fig. 6 - JEDEC TO-219AA plastic package designed for use as a direct replacement for the hermetically sealed JEDEC TO-3 transistor package.

The RCA high-power plastic package is also available with an attached header-case lead, as shown in Fig. 7. This three-lead package is designed for mounting on a printed-circuit board.

LEAD-FORMING TECHNIQUES

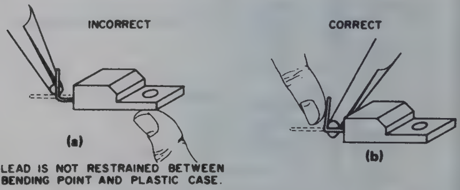
RCA Versawatt plastic packages are both rugged and versatile within the confines of commonly accepted standards for such devices. Although these versatile packages lend themselves to numerous arrangements, provision of a wide variety of lead configurations to conform to the specific requirements of many different mounting arrangements is highly impractical. However, the leads of the Versawatt in-line package can be formed to a custom shape, provided that they are not indiscriminately twisted or bent. Although these leads can be formed, they are not flexible in the general sense, nor are they sufficiently rigid for unrestrained wire wrapping.

Before an attempt is made to form the leads of an in-line package to meet the requirements of a specific application, the desired lead configuration should be determined, and a lead-bending fixture should be designed and constructed. The use of a properly designed fixture for this operation eliminates the need for repeated lead bending. When the use of a special bending fixture is not practical, a pair of long-nosed pliers may be used. The pliers should hold the lead firmly between the bending point and the case, but should not touch the case. Fig. 8 illustrates the use of long-nosed pliers for lead bending. Fig. 8(a) shows techniques that should be avoided; Fig. 8(b) shows the correct method.



ALL DIMENSIONS IN INCHES

Fig. 7 - TO-219AA plastic transistor package designed for mounting on printed-circuit boards.



LEAD IS NOT RESTRAINED BETWEEN BENDING POINT AND PLASTIC CASE.

Fig. 8 - Use of long-nosed pliers for lead bending: (a) incorrect method; (b) correct method.

When the leads of an in-line plastic package are to be formed, whether by use of long-nosed pliers or a special bending fixture, the following precautions must be observed to avoid internal damage to the device:

1. Restrain the lead between the bending point and the plastic case to prevent relative movement between the lead and the case.
2. When the bend is made in the plane of the lead (spreading), bend only the narrow part of the lead.
3. When the bend is made in the plane perpendicular to that of the leads, make the bend at least 1/8 inch from the plastic case.
4. Do not use a lead-bend radius of less than 1/16 inch.
5. Avoid repeated bending of leads.

The leads of the TO-220AB Versawatt in-line package are not designed to withstand excessive axial pull. Force in this direction greater than 4 pounds may result in permanent damage to the device. If the mounting arrangement tends to impose axial stress on the leads, some method of strain relief should be devised. Fig. 2 illustrates an acceptable lead-forming method that provides this relief.

Wire wrapping of the leads is permissible, provided that the lead is restrained between the plastic case and the point of the wrapping. Soldering to the leads is also allowed; the maximum soldering temperature, however, must not exceed 275^{o}C and must be applied for not more than 5 seconds at a distance greater than 1/8 inch from the plastic case. When wires are used for connections, care should be exercised to assure that movement of the wire does not cause movement of the lead at the lead-to-plastic junctions.

The leads of the RCA molded-plastic high-power packages are not designed to be reshaped. Simple bending of the leads, however, is permitted to change them from a standard vertical to a standard horizontal configuration, or conversely. Bending of the leads in this manner is restricted to three 90-degree bends; repeated bendings, therefore, should be avoided.

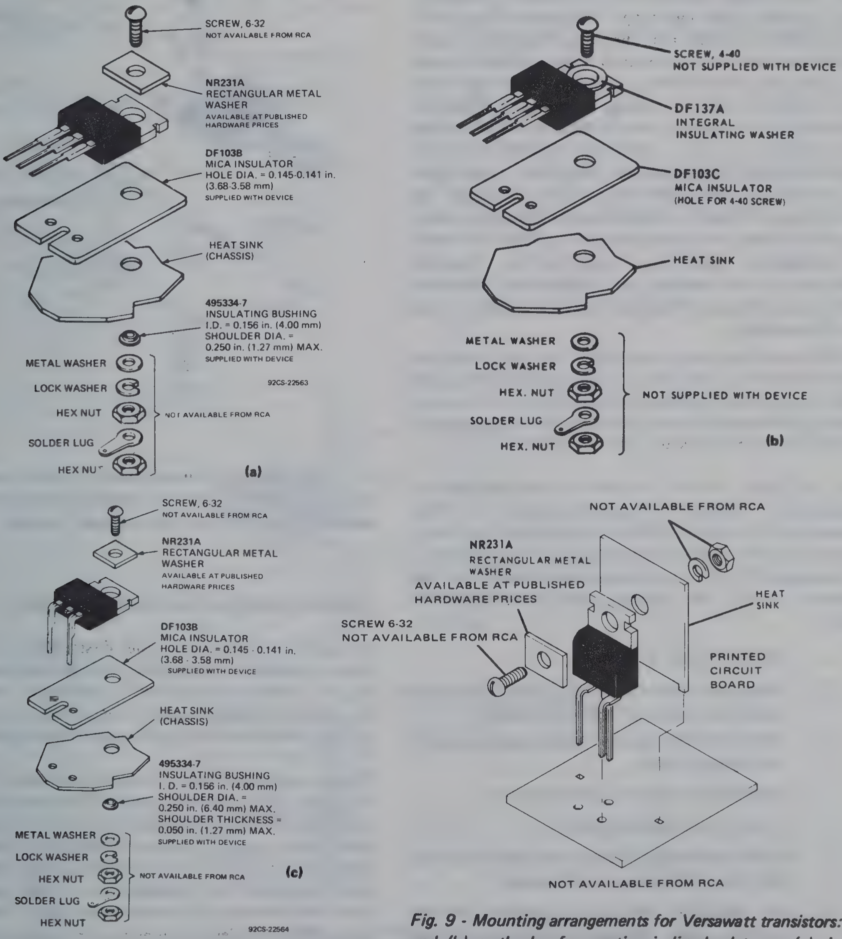

SCREW, 6-32
NOT AVAILABLE FROM RCA
NR231A
RECTANGULAR METAL WASHER
AVAILABLE AT PUBLISHED HARDWARE PRICES
DF103B
MICA INSULATOR
HOLE DIA. = 0.145-0.141 in. (3.68-3.58 mm)
SUPPLIED WITH DEVICE
HEAT SINK (CHASSIS)
495334-7
INSULATING BUSHING
I.D. = 0.156 in. (4.00 mm)
SHOULDER DIA. = 0.250 in. (1.27 mm) MAX.
SUPPLIED WITH DEVICE
METAL WASHER
LOCK WASHER
HEX NUT
SOLDER LUG
HEX NUT
NOT AVAILABLE FROM RCA
92CS-22563
(a)
SCREW, 4-40
NOT SUPPLIED WITH DEVICE
DF137A
INTEGRAL INSULATING WASHER
DF103C
MICA INSULATOR
(HOLE FOR 4-40 SCREW)
HEAT SINK
METAL WASHER
LOCK WASHER
HEX. NUT
SOLDER LUG
HEX. NUT
NOT SUPPLIED WITH DEVICE
(b)
SCREW, 6-32
NOT AVAILABLE FROM RCA
NR231A
RECTANGULAR METAL WASHER
AVAILABLE AT PUBLISHED HARDWARE PRICES
DF103B
MICA INSULATOR
HOLE DIA. = 0.145 - 0.141 in. (3.68 - 3.58 mm)
SUPPLIED WITH DEVICE
HEAT SINK (CHASSIS)
495334-7
INSULATING BUSHING
I. D. = 0.156 in. (4.00 mm)
SHOULDER DIA. = 0.250 in. (6.40 mm) MAX.
SHOULDER THICKNESS = 0.050 in. (1.27 mm) MAX.
SUPPLIED WITH DEVICE
METAL WASHER
LOCK WASHER
HEX NUT
SOLDER LUG
HEX NUT
NOT AVAILABLE FROM RCA
(c)
92CS-22564
NOT AVAILABLE FROM RCA
NR231A
RECTANGULAR METAL WASHER
AVAILABLE AT PUBLISHED HARDWARE PRICES
SCREW 6-32
NOT AVAILABLE FROM RCA
HEAT SINK
PRINTED CIRCUIT BOARD
NOT AVAILABLE FROM RCA

Fig. 9 - Mounting arrangements for Versawatt transistors: (a) and (b) methods of mounting in-line-lead types; (c) chassis mounting; (d) mounting on printed-circuit boards.

In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

MOUNTING

Fig. 9 shows recommended mounting arrangements and suggested hardware for the Versawatt transistors. The rectangular washer (NR231A) shown in Fig. 9(a) is designed to minimize distortion of the mounting flange when the transistor is fastened to a heat sink. Excessive distortion of the flange could cause damage to the transistor. The washer is particularly important when the size of the mounting hole exceeds 0.140 inch (6-32 clearance). Larger holes are needed to accommodate insulating bushings; however, the holes should not be larger than necessary to provide hardware clearance and, in any case, should not exceed a diameter of 0.250 inch. Flange distortion is also possible if excessive torque is used during mounting. A maximum torque of 8 inch-pounds is specified. Care should be exercised to assure that the tool used to drive the mounting screw never comes in contact with the plastic body during the driving operation. Such contact can result in damage to the plastic body and internal device connections. An excellent method of avoiding this problem is to use a spacer or combination spacer-isolating bushing which raises the screw head or nut above the top surface of the plastic body, as shown in Fig. 10. The material used for such a spacer or spacer-isolating bushing should, of course, be carefully selected to avoid "cold flow" and consequent reduction in mounting force. Suggested materials for these bushings are diallphthalate, fiberglass-filled nylon, or fiberglass-filled polycarbonate. Unfilled nylon should be avoided.

Modification of the flange can also result in flange distortion and should not be attempted. The transistor should not be soldered to the heat sink by use of lead-tin solder because the heat required with this type of solder will cause the junction temperature of the transistor to become excessive.

The TO-220AA plastic transistor can be mounted in commercially available TO-66 sockets, such as UID Electronics Corp. Socket No. PTS-4 or equivalent. For testing purposes, the TO-220AB in-line package can be mounted in a Jetron Socket No. CD74-104 or equivalent. Regardless of the mounting method, the following precautions should be taken:

1. Use appropriate hardware.
2. Always fasten the transistor to the heat sink before the leads are soldered to fixed terminals.
3. Never allow the mounting tool to come in contact with the plastic case.
4. Never exceed a torque of 8 inch-pounds.
5. Avoid oversize mounting holes.
6. Provide strain relief if there is any probability that axial stress will be applied to the leads.
7. Use insulating bushings to prevent hot-creep problems. Such bushings should be made of diallphthalate, fiberglass-filled nylon, or fiberglass-filled polycarbonate.

Fig. 11 shows the recommended hardware and mounting arrangements for RCA high-power molded-plastic transistors. These types can be mounted directly in a socket similar to that shown in Fig. 11(b). The precautions listed for the Versawatt packages should also be followed in the mounting of the high-power molded-plastic packages.

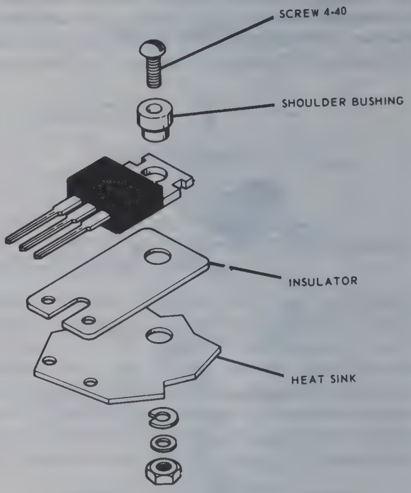


Fig. 10 - Mounting arrangements in which an isolating bushing is used to raise the head of the mounting screw above the plastic body of the Versawatt transistor.

THERMAL-RESISTANCE CONSIDERATIONS

The maximum allowable power dissipation in a solid-state device is limited by its junction temperature. An important factor to assure that the junction temperature remains below the specified maximum value is the ability of the associated thermal circuit to conduct heat away from the device.

When a solid-state device is operated in free air, without a heat sink, the steady-state thermal circuit is defined by the junction-to-free-air thermal resistance given in the published data on the device. Thermal considerations require that there be a free flow of air around the device and that the power dissipation be maintained below that which would cause the junction temperature to rise above the maximum rating. When the device is mounted on a heat sink, however, care must be taken to assure that all portions of the thermal circuit are considered.

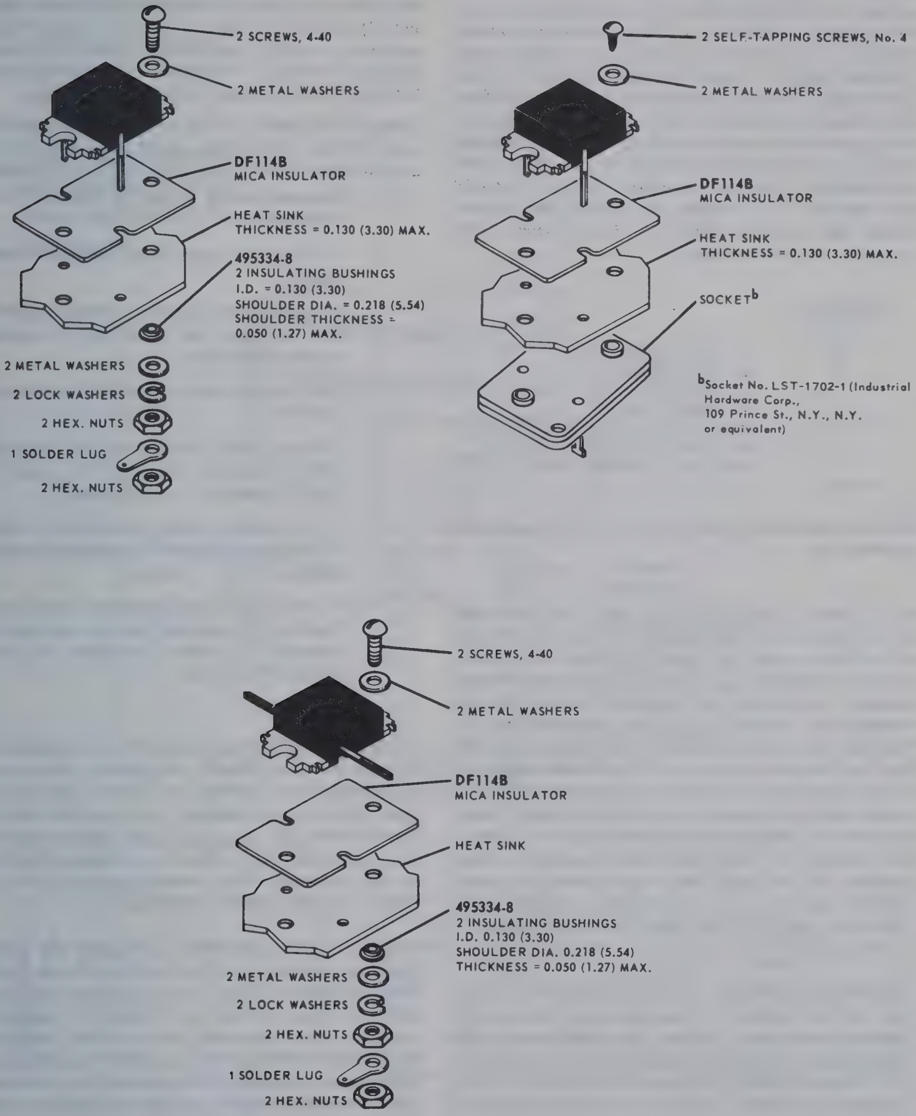
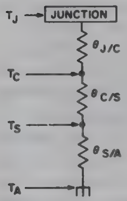

2 SCREWS, 4-40
2 METAL WASHERS
DF114B
MICA INSULATOR
HEAT SINK
THICKNESS = 0.130 (3.30) MAX.
495334-8
2 INSULATING BUSHINGS
I.D. = 0.130 (3.30)
SHOULDER DIA. = 0.218 (5.54)
SHOULDER THICKNESS = 0.050 (1.27) MAX.
2 METAL WASHERS
2 LOCK WASHERS
2 HEX. NUTS
1 SOLDER LUG
2 HEX. NUTS
2 SELF-TAPPING SCREWS, No. 4
2 METAL WASHERS
DF114B
MICA INSULATOR
HEAT SINK
THICKNESS = 0.130 (3.30) MAX.
SOCKETb
bSocket No. LST-1702-1 (Industrial Hardware Corp., 109 Prince St., N.Y., N.Y. or equivalent)
2 SCREWS, 4-40
2 METAL WASHERS
DF114B
MICA INSULATOR
HEAT SINK
495334-8
2 INSULATING BUSHINGS
I.D. 0.130 (3.30)
SHOULDER DIA. 0.218 (5.54)
THICKNESS = 0.050 (1.27) MAX.
2 METAL WASHERS
2 LOCK WASHERS
2 HEX. NUTS
1 SOLDER LUG
2 HEX. NUTS

Fig. 11 - Mounting arrangements for high-power plastic-package transistors: (a) chassis mounting; (b) socket mounting; (c) printed-circuit-board mounting.

Fig. 12 shows the thermal circuit for a heat-sink-mounted transistor. This figure shows that the junction-to-ambient thermal circuit includes three series thermal-resistance components, i.e., junction-to-case, $\theta_{J\text{-}C}$; case-to-heat-sink, $\theta_{C\text{-}S}$; and heat-sink-to-ambient, $\theta_{S\text{-}A}$. The junction-to-case thermal resistance of the various transistor types is given in the individual technical bulletins on specific types. The heat-sink-to-ambient thermal resistance can be determined from the technical data provided by the heat-sink manufacturer, or from published heat-sink nomographs. The case-to-heat-sink thermal resistance depends on several factors, which include the condition of the heat-sink surface, the type of material and thickness of the insulator, the type of thermal compound, the mounting torque, and the diameter of the mounting hole in the heat-sink.



T_J = junction temperature
T_C = case temperature
T_S = heat-sink temperature
T_A = ambient temperature
$\theta_{J/C}$ = junction-to-case thermal resistance
$\theta_{C/S}$ = case-to-heat-sink thermal resistance
$\theta_{S/A}$ = heat-sink-to-ambient thermal resistance

Fig. 12 - Thermal equivalent circuit for a transistor mounted on a heat sink.

Fig. 13 shows a set of curves of typical case-to-heat-sink thermal resistance of the Versawatt transistor as a function of mounting torque for several mounting arrangements. Curves A through D show typical case-to-heat-sink thermal resistance for the mounting arrangements shown in Figs. 9(a) through 9(d). Curves E and F are representative of a Versawatt transistor mounted over a heat-sink mounting hole that has a diameter of 0.140 inch (No. 6 screw clearance). Curve E shows the wide variation in thermal resistance with torque when the transistor is mounted dry. Curve F shows the effect on contact thermal resistance of a thin layer of Dow Corning No. 340 silicone grease applied between transistor and heat sink. For torques within the recommended range of 4 to 8 inch-pounds, contact thermal resistance is reduced to between 18 and 25 per cent of the dry values.

The curves shown in Fig. 14 represent typical case-to-heat-sink thermal resistance of the high-power molded-plastic transistor package as a function of mounting torque. The thermal resistances shown by curves A and C are representative of the mounting arrangements shown in Fig. 11(a) through 11 (c). Curves B and D are typical for mounting without mica over heat-sink mounting holes that have a diameter of 0.113 inch (No. 4 screw clearance). The effect of a thin layer of silicone grease on contact thermal resistance is illustrated by a comparison of curves B and D.

Operation of the transistor with heat-sink temperatures of 100°C or greater results in some shrinkage of the insulating bushing normally used to mount power transistors. The degradation of contact thermal resistance (refer to Figs. 13 and 14) is usually less than 25 per cent if a good thermal compound is used. (A more detailed discussion of thermal resistance, including nomographs, can be found in the **RCA Solid State Power Circuits**, Technical Series SP-52.)

During the mounting of RCA molded-plastic solid-state power devices, the following special precautions should be taken to assure efficient heat transfer from case to heat sink:

1. Mounting torque should be between 4 and 8 inch-pounds.
2. The mounting holes should be kept as small as possible.
3. Holes should be drilled or punched clean with no burrs or ridges, and chamfered to a maximum radius of 0.010 inch.
4. The mounting surface should be flat within 0.002 inch/inch.
5. Thermal grease (Dow Corning 340 or equivalent) should always be used (on both sides of the insulating washer if one is employed).
6. Thin insulating washers should be used (thickness of factory-supplied mica washers ranges from 2 to 4 mils).
7. A lock washer or torque washer should be used, together with materials that have sufficient creep strength to prevent degradation of heat-sink efficiency during life.

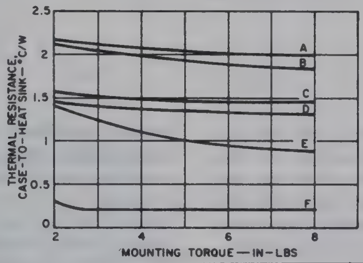
A wide variety of solvents is available for degreasing and flux removal. The usual practice is to submerge components in a solvent bath for a specified time. From a reliability standpoint, however, it is extremely important that the solvent, together with other chemicals in the solder-cleaning system (such as flux and solder covers), not adversely affect the life of the component. This consideration applies to all non-hermetic and molded-plastic components.

It is, of course, impractical to evaluate the effect on long-term transistor life of all cleaning solvents, which are marketed under a variety of brand names with numerous additives. These solvents can, however, be classified with respect to their component parts, as either acceptable or unacceptable. Chlorinated solvents tend to dissolve the outer package and, therefore, make operation in a humid atmosphere unreliable. Gasoline and other hydrocarbons cause the inner encapsulant to swell and damage the transistor. Alcohol is an acceptable solvent. Examples of suitable alcohols are: isopropanol, methanol, and special denatured alcohols, such as SDA1, SDA30, SDA34, and SDA44.

Care must also be used in the selection of fluxes in the oldering of leads. Rosin or activated rosin fluxes are ecommended, while organic or acid fluxes are not. Examples of acceptable fluxes are:

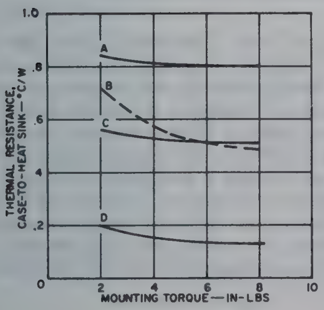
1. Alpha Reliaros No. 320-33
2. Alpha Reliaros No. 346
3. Alpha Reliaros No. 711
4. Alpha Reliafoam No. 807
5. Alpha Reliafoam No. 809
6. Alpha Reliafoam No. 811-13
7. Alpha Reliafoam No. 815-35
8. Kester No. 44

If the completed assembly is to be encapsulated, the effect on the molded-plastic transistor must be studied from both a chemical and a physical standpoint.



CURVE	MOUNTING ARRANGEMENT FIGURE	HEAT SINK HOLE DIA. (IN.)	MICA THICKNESS (MILS)	THERMAL COMPOUND
A	9(a)	.250	4	Dow Corning No.340
B	9(b)	.113	4	Dow Corning No.340
C	9(a)	.250	2	Dow Corning No.340
D	9(b)	.113	2	Dow Corning No.340
E	—	.140	None	None
F	—	.140	None	Dow Corning No.340

Fig. 13 - Typical case-to-heat-sink thermal resistance as a function of mounting torque for an RCA Versawatt transistor.



CURVE	MOUNTING ARRANGEMENT FIGURE	MICA THICKNESS (MILS)	THERMAL COMPOUND
A	11(a) thru 11(c)	4	Dow Corning No.340
B	—	None	None
C	11(a) thru 11(c)	2	Dow Corning No.340
D	—	None	Dow Corning No.340

Fig. 14 - Typical case-to-heat thermal resistance as a function of mounting torque for an RCA high-power plastic-package transistor.

RCA
Solid State
Division

Thyristors
Application Note
AN-4242

A Review of Thyristor Characteristics and Applications

by T.C. McNulty

Thyristors, both SCR's and triacs, are now widely accepted in power-control applications. With the emphasis in such applications placed on low cost, small package size, and circuit simplicity, thyristors satisfy these requirements with reliability exceeding that of electromechanical counterparts. This Note describes the operation, ratings, characteristics, and typical applications of these devices.

Types of Thyristors

Thyristors are semiconductor devices that have characteristics similar to those of thyratron tubes; more specifically, they are semiconductor switches whose bistable state depends on the regenerative feedback associated with a p-n-p-n structure. Basically, this group includes any bistable semiconductor device that has three or more junctions (i.e., four or more semiconductor layers) and can be switched from a high-impedance (OFF) state to a conducting (ON) state, and from the conducting (ON) state to the high-impedance (OFF) state, within at least one quadrant of the principal-voltage characteristics.

There are several types of thyristors, which differ primarily in number of electrode terminals and operating characteristics associated with the third quadrant (negative) of the voltage-current characteristics. Reverse-blocking triode thyristors, commonly called silicon controlled rectifiers (SCR's), and bidirectional triode thyristors, referred to as triacs, are the most popular types. Silicon controlled rectifiers have satisfied the requirements of many power-switching applications with much greater reliability than electromechanical or tube counterparts. As the use of SCR's in power applications increased, the need for complete ac control became apparent. The new family of thyristor devices generated to provide bidirectional current properties is referred to as triacs. A triac can be considered as two parallel SCR's (p-n-p-n) oriented in opposite directions to provide symmetrical bidirectional characteristics.

Two-Transistor Analogy

The bistable action of thyristors can be explained by analysis of the structure of an SCR. This analysis can be related to either operating quadrant of a triac because a triac is essentially two parallel SCR's oriented in opposite directions. A two-transistor analogy of an SCR is illustrated in Fig. 1. Fig. 1(a) shows the schematic symbol for an SCR, and Fig. 1(b) shows the p-n-p-n structure the symbol represents. In the two-transistor model for the SCR shown in Fig. 1(c), the interconnections of the two transistors are such that regenerative action can occur when a proper gate signal is applied to the base of the lower n-p-n transistor.

In the diagram of Fig. 2, the emitter of the upper (p-n-p) transistor is returned to the positive terminal of a dc supply through a limiting resistor R_2, and the emitter of the lower (n-p-n) transistor is returned to the negative terminal of the dc supply to provide a complete electrical path. When the model is in the OFF state, the initial principal-current flow is zero. If a positive pulse is then applied to the base of the n-p-n transistor, the transistor turns on and forces the collector (which is also the base of the p-n-p transistor) to a low potential; as a result, current (I_a) begins to flow. Because the p-n-p transistor is then in the active state, collector current ($I_{c1} = I_{b2}$) flows into the base of the n-p-n transistor and sets up the conditions for regeneration. If the external gate drive is removed, the model remains in the ON state as a result of the division of currents associated with the two transistors, provided that sufficient principal current (I_a) is available.

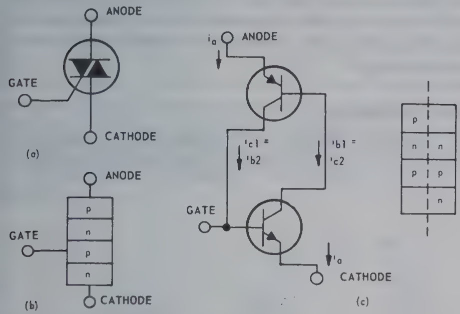


Fig. 1 - Two-transistor analogy of an SCR: (a) schematic symbol of SCR; (b) p-n-p-n structure represented by schematic symbol; (c) two-transistor model of SCR.

Theoretically, the model shown in Fig. 2 remains in the ON state until the principal current flow is reduced to zero. Actually, turn-off occurs at some value of current greater than zero. This effect can be explained by observation of the division of currents as the value of the limiting resistor is gradually increased. As the principal current is gradually reduced to the zero current level, the division of currents within the model can no longer sustain the required regeneration and the model reverts to the blocking state.

The two-transistor model illustrates three features of thyristors: (1) a gate trigger current is required to initiate regeneration, (2) a minimum principal current (referred to as "latching current") must be available to sustain regeneration, and (3) reduction of principal-current flow results in turn-off at some level of current flow (referred to as "holding current") slightly greater than zero.

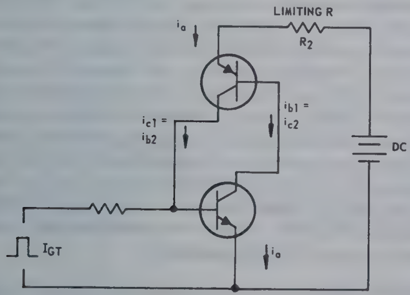


Fig.2 - Two-transistor model connected to show a complete electrical path.

Fig. 3 illustrates the effects on latching and holding current for resistive termination at the base of the n-p-n transistor. The collector current through the p-n-p transistor must be increased to supply both the base current for the n-p-n transistor and the shunt current through the terminating resistor. Because the principal-current flow must be increased to supply this increased collector current, latching and holding current requirements also increase. The use of the two-transistor model provides a more concise meaning to the mechanics of thyristors. In thyristor fabrication, it is generally good practice to use a low-beta p-n-p unit and to include internal resistance termination for the base of the n-p-n unit. Termination of the n-p-n unit provides immunity from "false" (non-gated) turn-on, and the use of the low-beta p-n-p units permits a wider base region to be used to support the high voltage encountered in thyristor applications.

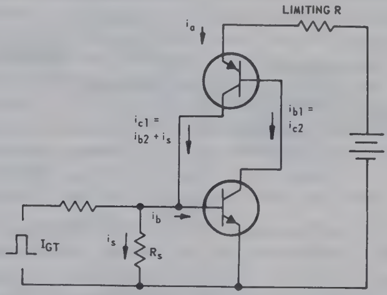


Fig.3 - Two-transistor model of SCR with resistive termination of the n-p-n transistor base.

Voltage and Temperature Ratings

The effects of temperature and voltage are important in thyristors because these devices possess regenerative action and are required to support high voltage in the OFF state. In the two-transistor model shown in Fig. 2, an increase in temperature causes a leakage current which, if allowed to migrate to the base of the n-p-n transistors, forces the transistor into the active region. Regenerative action then calls for additional leakage current, and causes the model to switch into the ON state and establish a principal-current flow. For reliable operation at high temperature, the base of the n-p-n transistor should be terminated with a low value of resistance to prevent turn-on as a result of high-temperature operation.

Because gate termination is required on all thyristors, RCA devices contain a diffused internal gate-cathode resistor (the so-called "shorted-emitter" design) and do not require external gate termination. Therefore, it is not necessary to specify an OFF-state rating under the conditions of external gate-resistance termination. The use of this internal shunt resistance improves the OFF-state blocking capability, provides increased immunity against false turn-on, and slightly increases gate-current requirements.

OFF-state voltage ratings of thyristors are specified for both steady-state and transient operation for both forward (positive) and reverse (negative) blocking conditions at the maximum junction temperature. For SCR's, voltages are considered to be forward (positive) when the anode is at a positive potential with reference to the cathode. Negative voltages are referred to as reverse-blocking voltages. For triacs, voltages are considered to be positive when main terminal 2 is at a positive potential with reference to main terminal 1; this condition is referred to as first-quadrant (I) operation. Third-quadrant (III) operation occurs when main terminal 2 is at a negative potential with reference to main terminal 1. Fig. 4 shows the principal voltage-current characteristics for both SCR's and triacs.

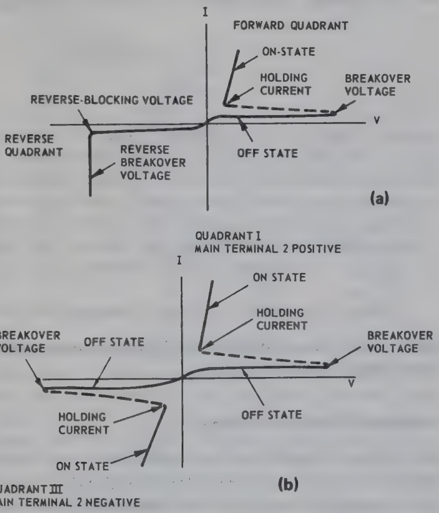


Fig.4 - Principal voltage-current characteristics of SCR's and triacs.

Operation of an SCR under reverse-blocking voltage is similar to that of a reverse-biased silicon rectifier or other semiconductor diodes. In this operating mode, the SCR exhibits a very high internal impedance, and a small reverse current flows through the p-n-p-n structure until the reverse breakdown voltage is reached, at which time the reverse current increases rapidly. For forward (positive) operation, the SCR is electrically bistable and exhibits either high impedance (forward-blocking or OFF state) or low impedance (forward-conducting or ON state). In the forward-blocking state, a small leakage current, considered to be of approximately the same value as that for reverse leakage, flows through the p-n-p-n structure. As the forward voltage is increased, a "breakdown" point is reached at which the forward current increases rapidly and the voltage across the SCR decreases abruptly to a very low voltage, referred to as the forward ON voltage. When the SCR is in the ON state, the forward current is limited primarily by the impedance of the external circuit. Increases in forward (principal) current are accompanied by only a slight change in ON-state voltage.

If the triac is considered as two parallel SCR's oriented in opposite directions to provide symmetrical current flow, the behavior of a triac under positive or reverse voltage operation is essentially the same as that of an SCR in the forward-blocking mode.

Gate Characteristics

The breakover voltage of a thyristor can be varied, or controlled, by injection of a signal at the gate terminal. Fig. 5 shows curves of breakover as a function of gate current for first-quadrant operation of an SCR. A similar set of curves can be drawn for both the first and the third quadrant to represent triac operation.

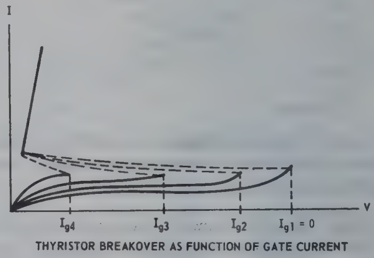


Fig.5 - Thyristor breakover as a function of gate current.

When the gate current I_g is zero, the applied voltage must reach the breakover voltage of the SCR or triac before switching occurs. As the value of gate current is increased, however, the ability of a thyristor to support applied voltage is reduced and there is a certain value of gate current at which the behavior of the thyristor closely resembles that of a rectifier. Because thyristor turn-on, as a result of exceeding the breakover voltage, can produce instantaneous power dissipation during the switching transition, an irreversible condition may exist unless the magnitude and rate of rise of principal current is restricted to tolerable levels. For normal operation, therefore, thyristors are operated at applied voltages lower than the breakover voltage, and are made to switch to the ON state by gate signals of sufficient amplitude to assure complete turn-on independent of the applied voltage. Once the thyristor is triggered to the ON state, the principal-current flow is independent of gate voltage or gate current, and the device remains in the ON state until the principal-current flow is reduced to a value below the holding current required to sustain regeneration.

The gate voltage and current required to switch a thyristor from its high-impedance (OFF) state to its low-impedance (ON) state at maximum rated forward anode current can be determined from the circuit shown in Fig. 6. Resistor R_2 is selected so that the anode current specified in the manufacturer's ratings flows when the device latches into its low-impedance or ON state. The value of R_1 is gradually decreased until the device under test is switched from its OFF state to its low-impedance or ON state. The values of gate current and gate voltage immediately prior to switching are the values required to trigger the thyristor. For an SCR, there is only one mode of gate firing capable of switching the device into the ON state, i.e., a positive gate signal for a positive anode voltage. If the gate polarity is reversed (negative voltage), the reverse current flow is limited by the value of R_2 and the gate-cathode internal shunt. The value of power dissipated for the reverse gate polarity is restricted to the maximum power-dissipation limit imposed by the manufacturer.

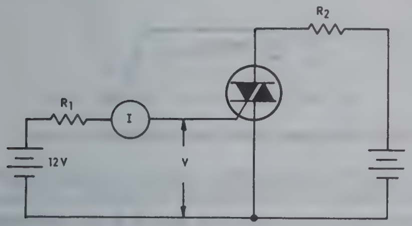


Fig.6 - Circuit used to measure thyristor gate voltage and current switching threshold.

Because of its complex structure, a triac can be triggered by either a positive or a negative gate signal regardless of the voltage polarity across the main terminals of the device. Fig. 7 illustrates the triggering mechanism and current flow within a triac. The gate trigger polarity is always referenced to main terminal 1. The potential difference between the two terminals is such that gate current flows in the direction indicated by the dotted arrow. The polarity symbol at main terminal 2 is also referenced to main terminal 1. The semiconductor materials between the various junctions within the pellet are labeled "p" and "n" to indicate the type of majority-carrier concentrations within the material.

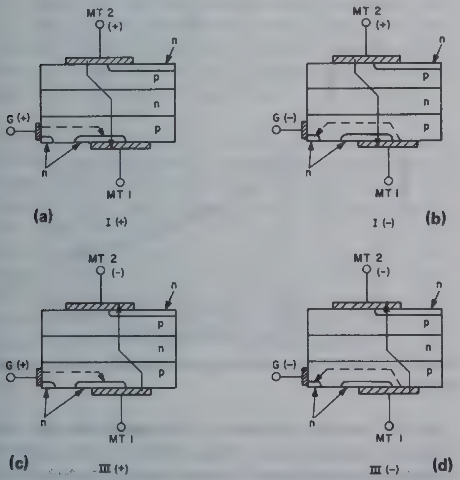


Fig.7 - Current flow in a triac.

For the various operating modes, the polarity of the voltage on main terminal 2 with respect to main terminal 1 is given by the quadrant in which the triac operates (either I or III), and the polarity of the gate signal used to trigger the device is given by the proper symbol next to the operating quadrant. For the I(+) operating mode, main terminal 2 and the gate are both positive with respect to main terminal 1. Initial gate current flows into the gate terminal, through the p-type layer, across the junction into the n-type layer, and out main terminal 1, as shown by the dotted arrow. As gate current flows, current multiplication occurs and the regenerative action within the pellet switches the triac to its ON state. Because of the polarities indicated between the main terminals, the principal current flows through the p-n-p-n structure as shown by the solid arrow. Similarly, for the other three operating modes, the initial gate-current flow is shown by the dotted arrow, and principal-current flow through the main terminals is shown by the solid arrow.

Because the direction of principal current influences the gate trigger current, the magnitude of the current required to trigger the triac differs for each mode. The operating modes in which the principal current is in the same direction as the gate current require less gate trigger current; modes in which the principal current is in opposition to the gate current require more gate trigger current.

Because triacs are bidirectional, they can provide full-cycle (360-degree) control of ac power from either a positive or a negative gate-drive signal. This feature is an advantage when it is necessary to control ac power from low-level logic systems such as integrated-circuit logic. With gate-power requirements for turn-on in the milliwatt region, triacs are capable of controlling power levels up to 10 kilowatts. Thus, the power gain associated with these thyristors far exceeds that of transistor counterparts in the semiconductor switching field.

Like many other semiconductor-device parameters, the magnitude of gate trigger current and voltage varies with the junction temperature. As thermal excitation of carriers within the semiconductor material increases, the increase in leakage current makes it easier for the device to be triggered by a gate signal. Therefore, the gate becomes more sensitive in all operating modes as the junction temperature increases. Conversely, if a triac or SCR is to be operated at low temperatures, sufficient gate trigger current must be provided to assure triggering of all devices at the lowest operating temperature expected in any particular application. Variations of gate-trigger requirements are given in the published data for individual thyristors.

The gate current specified in published data for thyristors is the dc gate trigger current required to switch an SCR or triac into its low-impedance state. For practical purposes, this dc value can be considered equivalent to a pulse current that has a minimum pulse width of 50 microseconds. For gate-current pulse widths smaller than 50 microseconds, the pulse-current curves associated with a particular device should be used to assure turn-on.

When pulse triggering of a thyristor is required, it is always advantageous to provide a gate-current pulse that has a magnitude exceeding the dc value required to trigger the device. The use of large trigger currents reduces variations in turn-on time, increases di/dt capability, minimizes the effect of temperature variation on triggering characteristics, and makes possible very short switching times. When a thyristor is initially triggered into conduction, the current is confined to a small area which is usually the more sensitive part of the cathode. If the anode current magnitude is great, the localized instantaneous power dissipation may result in irreversible damage unless the rate of rise of principal current is restricted to tolerable levels to allow time for current spreading over a larger area. When a much larger gate signal is applied, a greater part of the cathode is turned on initially; as a result, turn-on time is reduced, and the thyristor can support a much larger peak anode inrush current.

Switching Characteristics

Ratings of thyristors are based upon the amount of heat generated within the device pellet and the ability of the device package to transfer the internal heat to the external case. For high-performance applications in which switching of high peak current values but narrow pulse widths is desired, the internal energy dissipated during the turn-on process must be determined to assure that power dissipation is within ratings.

When thyristors (either triacs or SCR's) are triggered by a gate signal, the turn-on time consists of two stages, a delay time t_d and a rise time t_r, as shown in Fig. 8. The total turn-on time t_{gt} is defined as the time interval between the initiation of the gate signal and the time for the principal anode current flow through the thyristor to reach 90 per cent of its maximum value for a resistive load. The delay time t_d is defined as the time interval between the 50-per-cent point of the leading edge of the gate trigger voltage and the 10-per-cent point of the principal current for a resistive load. The rise time t_r is the time interval required for the principal current to rise from 10 to 90 per cent of its maximum value. The total turn-on time t_{on} is the sum of both delay and rise time ($t_d + t_r$).

Although the thyristor is affected to some extent by the peak off-state voltage and the peak on-state current level, the turn-on time is influenced primarily by the magnitude of the gate-trigger pulse current, as shown in Fig. 9. Faster turn-on time for larger gate drive is a result of a decrease in delay time associated with the thyristor because of the increased current density at the gate-cathode periphery. Of major importance in the turn-on time interval is the relationship between thyristor voltage and principal current flow through the thyristor. During the turn-on interval, the dynamic voltage drop is high and the current density can produce localized hot spots in the pellet area. Therefore, it is important that power dissipation during turn-on be restricted to levels within device specifications.

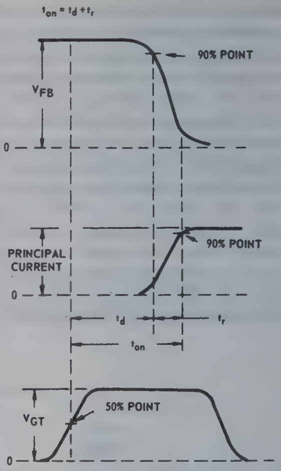


Fig.8 - Waveshapes illustrating thyristor turn-on time.

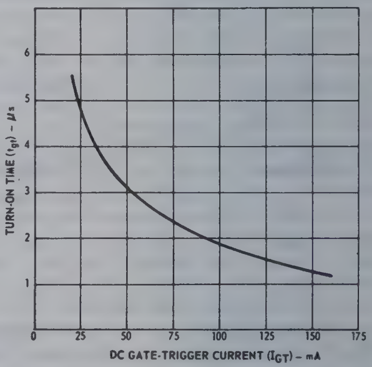


Fig.9 - Thyristor turn-on time as a function of gate trigger current.

Turn-off time of a thyristor can be associated only with SCR's. In triacs, a reverse voltage cannot be used to provide circuit-commutated turn-off voltage because a reverse voltage applied to one half of the triac structure would be a forward-bias voltage to the other half. For turn-off times in an SCR, the recovery period consists of two stages, a reverse recovery time and a gate recovery time, as shown in Fig. 10.

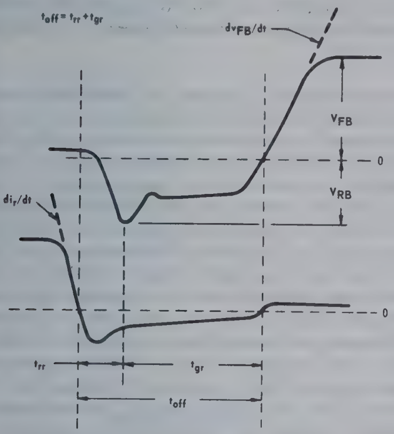


Fig. 10 - Waveshapes illustrating thyristor turn-off time.

When the forward current of an SCR is reduced to zero at he end of a conduction period, application of reverse voltage between the anode and cathode terminals causes reverse current to flow in the SCR until the time that the reverse current passes its peak value to a steady-state level called the everse recovery time t_{rr}. A second recovery period, called he gate recovery time, t_{gr}, must then elapse for the orward-blocking junction to establish a depletion region so hat forward-blocking voltage can be reapplied and successully blocked by the SCR. The gate recovery time of an SCR s usually much longer than the reverse recovery time. The otal time from the instant reverse recovery current begins to low to the start of the forward- blocking voltage is referred o as circuit-commutated turn-off time t_q.

Turn-off time depends upon a number of circuit parameters, ncluding on-state current prior to turn-off, rate of change of urrent during the forward-to-reverse transition, reverselocking voltage, rate of change of reapplied forward voltage, ate trigger level, the gate bias, and junction temperature. unction temperature and on-state current have a more ignificant effect on turn-off than any of the other factors. With turn-off time specified on the manufacturer's data sheet nd dependent upon the conditions as outlined above, urn-off time specification is only meaningful if all of the bove critical parameters are available in the actual application.

or applications in which an SCR is used to control 60-Hz ac ower, the entire negative half of the sine wave is a turn-off ondition and more than adequate for complete turn-off. For pplications in which the SCR is used to control the output of a full-wave rectifier bridge, however, there is no reverse voltage available for turn-off, and complete turn-off can be accomplished only if the bridge output is reduced to zero volts or the principal current is reduced to a value lower than the device holding current.

Because turn-off times are not associated with triacs due to the physical structure of the device, a new term is introduced called "critical rate of rise of commutation voltage", or the ability of a triac to commutate a fixed value of current under specified conditions. The rating can be explained by consideration of two SCR's in an inverse parallel mode, as shown in Fig. 11. SCR-1 is assumed to be in the conducting state with forward current established. As the principal current flow crosses the zero reference point, a small reverse current flows in SCR-1 until the time that the SCR reverts to the OFF state. The principal current is then diverted to SCR-2, provided that sufficient gate current is available to that device.

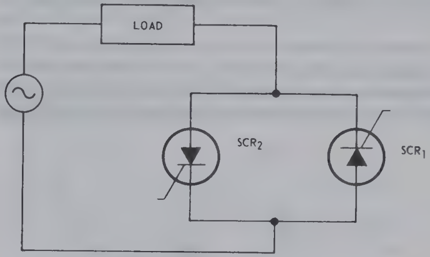


Fig. 11 - Circuit used to demonstrate critical rate of rise of commutation voltage.

The structure of a triac shown in Fig. 12 indicates that the main blocking junctions are common to both halves of the device. When the first half of the triac structure (SCR-1) is in the conducting state, a quantity of charge accumulates in the n-type region as a result of the principal current flow. As the principal current crosses the zero reference point, a small

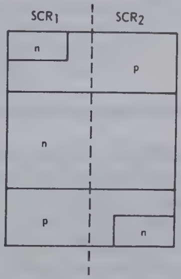


Fig. 12 - Structure of a triac.

reverse current is established as a result of the charge remaining in the n-type region. Because the n-type region is common to both halves of the devices, this reverse recovery current becomes a forward current to the second half of the triac. The current resulting from stored charge may cause the second half of the triac to go into the conducting state in the absence of a gate signal. Once current conduction has been established by application of a gate signal, therefore, complete loss in power control can occur as a result of interaction within the n-type base region of the triac unless sufficient time elapses to assure turn-off. It is imperative that triac manufacturers provide sufficient information regarding commutating capability under maximum current and case-temperature conditions so that triac control of ac power for resistive loading in a 60-Hz power source can be assured.

Commutation of triacs is more severe with inductive loads than with resistive loads because of the phase lag between voltage and current associated with inductive loads. Fig. 13 shows the waveforms for an inductive load with lagging current power factor. At the time the current reaches zero crossover (point A), the half of the triac in conduction begins to commutate when the principal current falls below the holding current required to sustain regeneration. Because the high-voltage junction is common to both halves of the triac, the stored charge can be neutralized only by recombination. At the instant the conducting half of the triac turns off, an applied voltage opposite to the current polarity is applied across the triac terminals (point B). Because this voltage is a forward bias to the second half of the triac, the sudden reapplied voltage in conjunction with the remaining stored charge in the high-voltage junction reduces the over-all device capability to support a fast rate of rise of applied voltage. The result is a loss of power control to the load, and the device remains in the conducting state in absence of a gate signal. Therefore, it is imperative that some means be provided to restrict the rate of rise of reapplied voltage to a value which will permit triac turn-off under the conditions of inductive load.

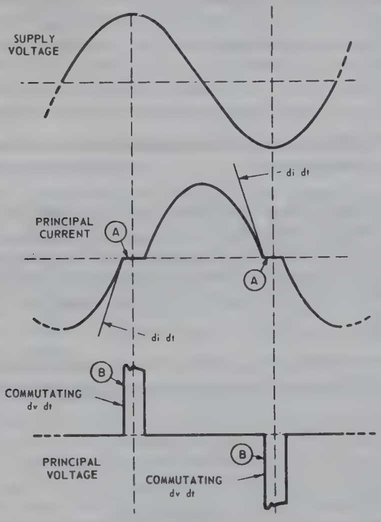


Fig. 13 - Waveshapes of commutating dv/dt characteristics.

An accepted method for keeping the commutating dv/dt within tolerable levels during triac turn-off is to use an RC snubber network in parallel with the main terminals of the triac. Because the rate of rise of applied voltage at the triac terminal is a function of the load impedance and the RC snubber network, the circuit can be evaluated under worst-case conditions of operating case temperature, maximum principal current, and any value of conjunction angle. The values of resistance and capacitance in the snubber are then adjusted so that the rate of rise of commutating dv/dt stress is within the specified minimum limit under any of the conditions mentioned above. The value of snubber resistance should be high enough to limit the snubber capacitance discharge currents during turn-on and dampen the LC oscillation during commutation (turn-off). Any combination of snubber resistance and capacitance that provides the requirements outlined above is considered satisfactory.

Some of the factors affecting commutating dv/dt capability of triacs are temperature, current magnitude, rate of change of current during commutation, and frequency of the applied principal current. With frequency directly related to commutating di/dt, early triac use was restricted to 60-Hz applications. Continued technological advances in triac device structure has resulted in faster "turn-off" capability and made possible a new family of triacs having 400-Hz commutating capability that is now being offered to circuit designers who must work with 400-Hz source voltages.

Another important parameter for thyristors is the "critical rate of rise of off-state voltage". A source voltage can be suddenly applied to an SCR or a triac which is in the OFF state through either closure of an ac line switch or transient voltages as a result of an ac line disturbance. If the fast rate of rise of the transient voltage exceeds the device rating, the thyristor may switch from the OFF state to the conducting state in the absence of a gate signal. If the thyristor is controlling alternating voltage, "false" turn-on (non-gated) resulting from a transient imposed voltage is limited to no more than half the applied voltage because turn-off occurs during the zero current crossing. However, if the source voltage suddenly applied to the OFF thyristor is a dc voltage, the device may switch to the ON state and turn-off could then be achieved only by circuit interruptions. The switching from the OFF state is caused by the internal capacitance of the thyristor. A steep-rising voltage dv/dt impressed across the terminals of a thyristor causes a capacitance-charging current to flow through the device. This charging current ($i=Cdv/dt$) is a function of the rate of rise of applied off-state voltage. If the rate of rise of voltage exceeds a critical value, the capacitance-charging current exceeds the gate trigger current and causes device turn-on. Operation at elevated junction temperatures reduces the thyristor ability to support a steep rising voltage dv/dt because less gate current is required for turn-on. The effect of temperature on the critical rate of rise of off-state voltage is shown in Fig. 14.

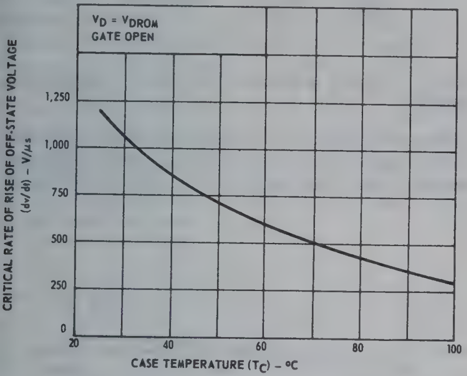


Fig. 14 - Critical rate of rise of off-state voltage as a function of case temperature.

Voltage transients which occur in electrical systems as a result of disturbance on the ac line caused by various sources such as energizing transformers, load switching, solenoid closure, contactors, and the like may generate voltages which are above the ratings of thyristors and result in spike voltages exceeding the critical rate of rise of off-state voltage capability. Thyristors, in general, switch from the OFF state to the ON state whenever the breakover voltage of the device is exceeded, and energy is then transferred to the load. Good practice in the use of thyristors exposed to a heavy transient environment is to provide some form of transient suppression.

For applications in which low-energy, long-duration transients may be encountered, it is advisable to use thyristors that have voltage ratings greater than the highest voltage transient expected in the system to provide protection against destructive transients. The use of voltage clipping cells is also effective. In either case, analysis of the circuit application will reveal the extent to which suppression should be employed. In an SCR application in which there is a possibility of exceeding the reverse-blocking voltage rating, it is advisable to add a clip cell or to use an SCR with a higher reverse-blocking voltage rating to minimize power dissipation in the reverse mode. Because triacs generally switch to a low conducting state, if the di/dt buildup of the principal current flow after turn-on is within device ratings it is safe to assume that reliable operation will be achieved under the specified conditions.

The use of an RC snubber is most effective in reducing the effects of the high-energy short-duration transients more frequently encountered in thyristor applications. When an RC snubber is added at the thyristor terminals, the rate of rise of voltage at the terminals is a function of the load impedance and the RC values used in the network. In some applications, "false" (non-gated) turn-on for even a portion of the applied voltage cannot be tolerated, and circuit response to voltage transients must be determined. An effective means of generating fast-rising transients and observing the circuit response to such transients is shown in Fig. 15. This circuit makes use of the "splash" effects of a mercury-wetted relay to transfer a capacitor charge to the input terminals of a control circuit. This approach permits generation of a transient of known magnitude whose rate of rise of voltage can easily be displayed on an oscilloscope. For a given load condition, the values in the RC snubber network can be adjusted so that the transient voltage at the device terminals is suppressed to a tolerable level. This approach affords the circuit designer with meaningful information as to how a control circuit will respond in a heavy transient environment. The circuit is capable of generating transient voltages in excess of 10 kilovolts per microsecond, which exceeds industrial generated transients. The response of a 100-millihenry solenoid control circuit exposed to a fast-rising transient is shown in Fig. 16.

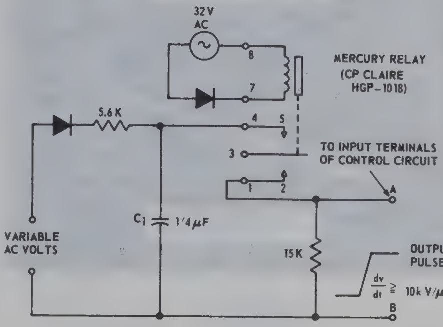


Fig. 15 - Circuit used to generate-fast rising transients.

Use of Diacs For Control Triggering

Basically, thryristors are current-dependent devices, and the magnitude of gate current I_{GT} and voltage V_{GT} required to trigger a thyristor into the on-state varies. The point at which thyristor triggering occurs depends not only on the required gate current and voltage, but also on the trigger source impedance and voltage. Fig. 17 shows a family of curves representing the gate-circuit load line between the open-circuit source voltage and the short-circuit current for different time intervals. In a circuit which applies time-dependent variable voltage Vac to a load and the gate trigger current required to trigger the thyristor is derived from the same source Vac, devices that have a gate current I_{gl} are

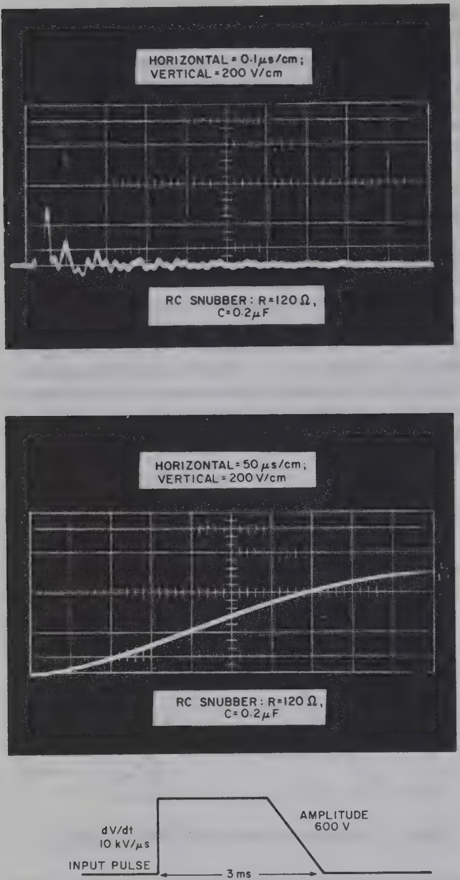


Fig. 16 - Waveforms showing response of a 100-millihenry solenoid control circuit to a fast-rising transient.

triggered earlier in the ac cycle than devices that have a higher gate trigger current Fig. 3. Although the circuit is capable of providing variable power to the load, it is heavily dependent on the gate current distribution, and results in uncontrolled conduction angles for a given value of gate series resistance. Furthermore, the circuit does not provide the recommended gate-current overdrive for switching of the fast-rising high-amplitude load currents present in resistive loading. A more efficient circuit for control of variable power to a load that eliminates the need for tight gate-current distribution uses a solid-state trigger device, called a diac, which is voltage dependent.

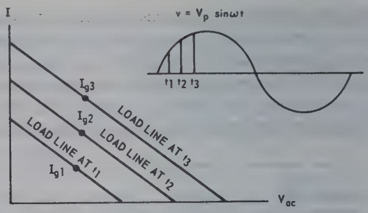


Fig. 17 - Thyristor gate-circuit load line for different time intervals.

The diac, often referred to as a bidirectional trigger diode, is a two-terminal, three-layer, transistor-like structure that exhibits a high-impedance blocking state up to a breakover voltage $V_{(BO)}$, above which the device enters a negative-resistance region. The characteristic curve in Fig. 18 shows the negative characteristics associated with diacs when they are exposed to voltages in excess of the breakover voltage $V_{(BO)}$. Because of their bidirectional properties and breakover voltage level, diacs are useful in triac control circuits in which variable power is to be supplied to a load. Because of their negative characteristic slope, diacs can also be used with capacitors to provide the fast-rising high-magnitude trigger current pulses recommended in thyristor applications which require efficient gate turn-on for the purpose of switching high-level load currents.

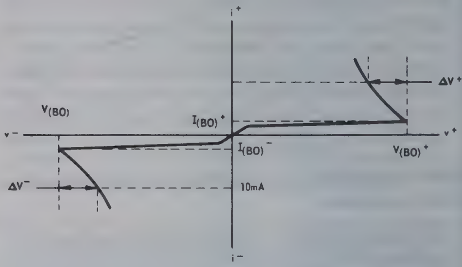


Fig. 18 - Diac voltage-current characteristic.

In normal applications, diacs are used in conjunction with RC phase networks to trigger triacs, as shown in Fig. 19. The

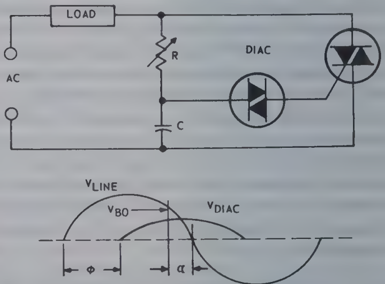


Fig. 19 - Use of diac with RC phase network to trigger triac.

RC phase network provides an initial phase-angle displacement ϕ so that conduction angles in excess of 90 degrees can be realized. As the voltage on the capacitor begins to build up in a sinusoidal manner, the breakover voltage $V_{(BO)}$ of the diac is reached, the triac is turned on, and a portion of the ac input voltage is provided to the load, as represented by the angle α. As previously mentioned, the diac offers a negative-resistance region and is capable of providing current pulses whose magnitude and pulse width are a function of the capacitor C and the combined impedance of the diac and the gate and main terminal of the triac. When the voltage on the capacitor C reaches the breakover voltage $V_{(BO)}$, the capacitor does not discharge completely, but is restricted to some finite level as a result of the diac negative-impedance characteristic at high values of pulse current. Fig. 20 shows the peak pulse current of a diac as a function of the capacitances of the phasing capacitor C.

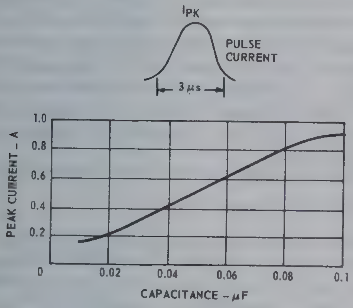


Fig.20 - Peak pulse current of a diac as a function of phasing capacitance.

Power Control Using Thyristors

n the control of ac power by means of semiconductor evices, emphasis has been placed on circuit simplicity, low ost, and small over-all package size. Thyristors meet these oals, and are also capable of providing either fixed or djustable power to the load. Fixed power is achieved by use f the thyristor as an ON-OFF switch, and adjustable power hrough the use of an RC phase network which provides ariable phase-gating operation. The following section discusses both SCR and triac circuit operations, and analysis of CR and triac behavior for various circuit conditions.

Many fractional-horsepower motors are series-wound universal" motors capable of operation from either an ac or dc source. In the early stages of thyristor control, SCR's ound wide acceptance in the control of universal motors, articularly in the portable power tools market. SCR's are apable of providing speed control over half of an ac sine ave, and, if full power is required, a simple shorting switch cross the SCR provides the necessary function; such a witch is shown in Fig. 21. Turn-off parameters for this circuit are not critical because the SCR has a half-cycle of applied negative voltage in which to recover. The SCR provides a reliable, highly efficient, long-life control for half-wave control circuits.

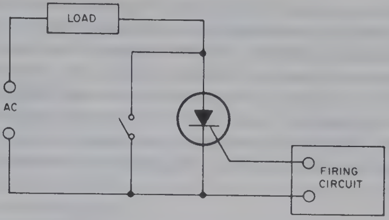


Fig.21 - Simple SCR half-wave control circuit.

Fig. 22 shows a full-wave bridge that feeds a resistive load and uses an SCR as the control element for load current. Power control is accomplished by SCR turn-on at various conduction angles with respect to the applied voltage. The criteria for turn-off in this circuit is important because the SCR must recover its forward-blocking state during the time that the forward current stops flowing. Although this time interval may appear to be very small, close analysis of the voltage wave during the transition time in which the full-wave bridge reverses direction reveals that substantial time exists for turn-off.

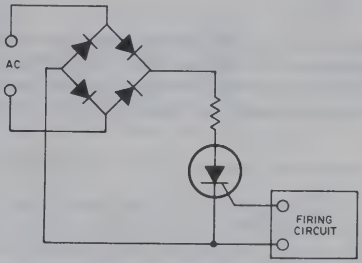


Fig.22 - Full-wave SCR bridge circuit.

Fig. 23 shows one-half of the bridge during the time that the forward current is approaching zero current. Two diodes are in series with the SCR; it is generally accepted that a diode

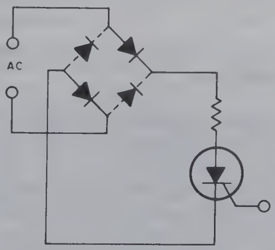


Fig.23 - Half of bridge circuit of Fig. 22 when forward current approaches zero for a resistive load.

voltage of approximately 0.6 volt is required to maintain each diode in conduction. If it is further assumed that a voltage of approximately 0.6 volt is required across the SCR to maintain conduction, the sum of the voltage drops over the circuit requires 1.8 volts; below this value, the SCR drops out of conduction. As the bridge reverses current direction, the same analysis holds true, i.e., forward conduction current is not resumed until the sum of the voltage drops exceeds 1.8 volts.

The waveform during the interval that the voltage wave goes from 1.8 volts to zero can be analyzed by reference to Fig. 24. A half-cycle (180 degrees) of conduction requires 8.3 milliseconds, one degree being equal to approximately 46 microseconds. Because a sine wave is linear for very small angles, a graph can be constructed to show the time interval during which the voltage is less than 1.8 volts for various magnitudes of applied voltage. Analysis of the voltage wave for an angle of one degree shows that an input voltage of 120 volts rms results in a voltage equal to 2.9 volts, which decays to zero in 46 microseconds. Because the SCR is non-conducting below a circuit threshold of 1.8 volts, a time of 28.5 microseconds then elapses while the voltage decays from 1.8 volts to zero. An equal time is required for the bridge to build up to the threshold voltage of 1.8 volts. Therefore, a total exposure time of 57 microseconds elapses in which the SCR is allowed to regain its forward-blocking state.

As shown in Fig. 24, increasing the magnitude of the applied voltage source to 240 volts rms cuts in half the time interval which the SCR is allowed for turn-off. Further increases in input voltage magnitude result in shorter turn-off periods.

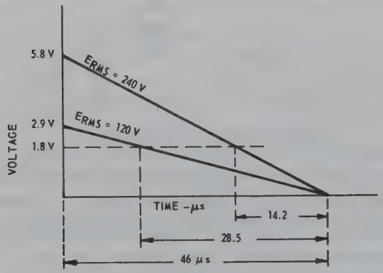


Fig.24 - Waveform of circuit in Fig. 22 as voltage wave goes from 1.8 volts to zero.

This analysis gives a clear, well-defined picture of the turn-off time available for a resistive load. However, for reactive loads, such as fractional-horsepower motors, the turn-off conditions, including turn-off time and dv/dt stress, are more difficult to define because they are affected by a number of variables, including the back EMF of the motor, the ratio of inductance to resistance, the motor loading, and the phase angle of motor current to source voltage. Normally, turn-off times for SCR's are industry-standardized to include peak forward current, rate of rise of reverse current, peak forward blocking voltage applied, and rate of rise of applied blocking voltage. The presence of the applied reverse current helps to shorten turn-off times because the reverse current sweeps out the charge in the blocking junction. For SCR operation from a full-wave bridge in which there is no appreciable reverse voltage available, turn-off is accomplished through recombination, and the effects of circuit loading on SCR operation must be clearly evaluated.

Full-wave ac switching can also be performed by use of two SCR's in an inverse parallel mode, often referred to as a "back-to-back" SCR pair, as shown in Fig. 25. This circuit can be used as a simple static switch or as a variable phase control circuit. It does not make use of a full-wave diode bridge, but simply uses the SCR's in an alternating mode. The circuit has the disadvantage of separate trigger logic, but possesses an inherent advantage in higher-frequency applications because advantage can be taken of the periods of the alternating voltage in which either device may recover to its blocking state. During the half-cycle of the applied voltage that SCR-1 is conducting, SCR-2 is reverse-biased and can recover its blocking state. Because of the applied reverse voltage and associated time of the half-cycle voltage, turn-off times are not critical.

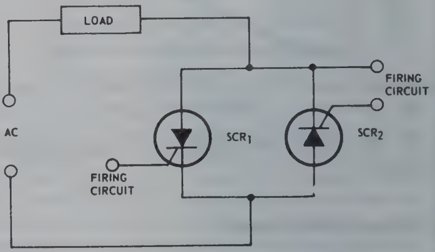


Fig.25 - Full-wave ac switching circuits using a "back-to-back" SCR pair.

This two-SCR circuit is often favored over a triac circuit even though separate trigger sources are required, because i is supposed to have better commutating capability. Fig. 2 shows the waveforms of commutating dv/dt for the SC circuit. If the load is inductive with lagging current powe factor, the conducting SCR commutates at the time th principal current reaches zero crossover (point A) and revert to the blocking state; a reapplied voltage of opposite polarit equal to the source voltage then appears across the non conducting SCR. Because this voltage is a forward-bia voltage to the non-conducting SCR, device turn-on can occu if the rate of rise of applied forward voltage exceeds th device rating for critical rate of rise of off-state voltage. Fo inductive loading in an inverse-parallel-mode SCR applica tion, power control to the load can be lost if the rate of ris of applied voltage is exceeded.

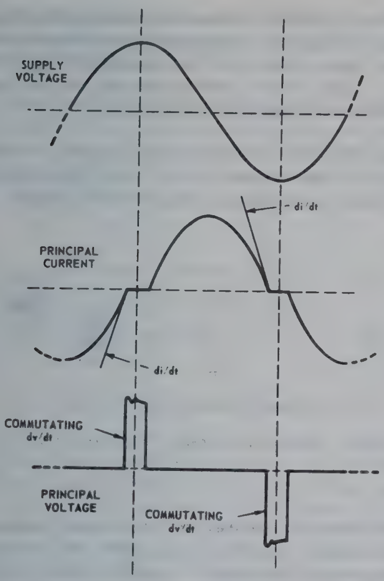


Fig.26 - Waveforms of commutating dv/dt for SCR circuit of Fig. 25.

Although it may appear that the rate of rise is extremely fast, closer circuit evaluation reveals that the dv/dt stress is restricted to some finite value which is a function of the load reactance L and the device capacitance C. Therefore, it is important that the rate of rise of applied voltage during commutation not exceed the device specification for critical rate of rise of off-state voltage under worst-case condition or unreliable operation may result. It is generally good practice in inverse-parallel operation to use an RC snubber network across the SCR pair to limit the rate of rise to some finite value below the minimum requirements, not only to limit the voltage rise during commutation, but also to suppress transient voltage that may occur as a result of ac line disturbances.

As previously mentioned, the use of semiconductor devices for ac power control has emphasized circuit simplicity, low cost, and small over-all package size. The development of the bidirectional triode thyristor, referred to as a triac, achieved ll of these goals. Triacs can perform the same functions as two SCR's for full-wave operation, and also simplify gate logic requirements for triggering.

A simple, inexpensive triac circuit that can provide variable power to a load over a full cycle of applied voltage is the light-dimmer circuit. This circuit contains a diac, a triac, and n RC phase-control network. The basic light-dimmer circuit s described below because it provides a good example of triac behavior as related to load requirements and of the operation of a diac in an RC phase-control circuit.

Fig. 27 shows the basic triac-diac light-dimmer control circuit with the triac connected in series with the load. During the beginning of each half-cycle, the triac is in the off-state and the entire line voltage is across the triac; therefore, no voltage appears across the load. (Actually, there is some voltage across the load as a result of triac leakage currents, which are a function of applied voltage and junction temperature. However, these leakage currents are relatively small, at most in the milliampere range, and the resulting load voltages are generally ignored.)

The RC charge-control circuit is in parallel with the control triac, and the applied voltage serves to charge the timing capacitor C through the variable resistor R. When the voltage across C reaches the breakover voltage $V_{(BO)}$ of the diac, the capacitor discharges through the diac and the gate-to-main-terminal-1 impedance of the triac and turns on the control triac. At this point, the line voltage is transferred to the load for the remainder of the applied half-cycle voltage. As the load current reverses direction (zero crossing), the triac turns off and reverts to the blocking state. This sequence of events is repeated for every following half-cycle of applied voltage.

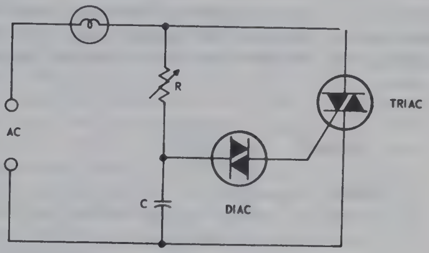


Fig.27 - Basic triac-diac light-dimmer control circuit.

If the value of resistance R is decreased, the capacitor charges to the breakover voltage $V_{(BO)}$ of the diac earlier in the ac cycle; the power supplied to the load is then increased and the lamp intensity is effectively increased. If the value of resistance R is increased, triac triggering occurs later in the ac cycle and applied voltage to the load is reduced; the result is decreased lamp intensity. Therefore, changes in the resistance value R effectively apply variable power to a load (which is a lamp load in the circuit of Fig. 27, but could also be a motor load or heating element).

Although the load is arbitrarily placed in series with main terminal 2, the circuit performs equally as well if the load is shifted to main terminal 1. (Actually, any commercial lamp dimmer available has two wires brought out for external connection, and the chance that the load will be connected to main terminal 1 is 50 per cent.) The only requirements for reliable operation are that the RC phase network be in parallel with the triac and that capacitor-discharge loop currents be directed from the diac to the triac gate and main terminal 1. Although the basic light-control circuit operates with the component arrangement shown in Fig. 27, additional components are often added to reduce hysteresis effects, extend the effective range of power control, and suppress radio-frequency interference.

Hysteresis in triac phase-control circuits is referred to as the ratio of applied load voltage when the triac initially turns on (as control potentiometer is slowly reduced from some high value) to the value of load voltage prior to "extinguishing" (as the control potentiometer is slowly increased to some higher value). If the circuit has high hysteresis, the control potentiometer travel may be as high as 25 per cent before triac turn-on occurs, after which the control potentiometer may be turned back 15 per cent before the triac "extinguishes". Hysteresis is an undesirable feature if the circuit application requires low-level lamp illumination because a momemtary drop in line voltage may result in the triac "extinguishing" or missing one half-cycle of applied voltage when the capacitor voltage is barely equal to the breakover voltage $V_{(BO)}$ of the diac. If this condition exists, the control potentiometer must be reduced to "start up" the triac again.

Hysteresis is a result of the capacitor discharging through the diac and not recovering the original voltage prior to triggering. Fig. 28 shows the waveforms of the charging capacitor C as related to the applied line voltage. The initial displacement angle ϕ is a result of the phase angle due to the value of the RC components used. As the value of the control potentiometer is slowly reduced, the value of charging voltage reaches the breakover voltage $V_{(BO)}$ of the diac, and the triac allows that portion of the ac wave remaining to appear at the load, as represented by the shaded area at the first trigger point. At this point, there is an abrupt change in capacitor voltage (Δ V). Therefore, as the capacitor charge reverses direction, the second trigger point is reached much earlier in the next half-cycle, and that portion of the ac wave remaining appears across the load, as represented by the shaded area at the second trigger point. The second trigger point and subsequent trigger points represent the steady-state level at which triggering occurs. Some reduction in hysteresis can be realized by inserting a resistor in series with the diac to reduce the effective diac negative resistance and minimize the change in capacitor voltage. However, this change reduces the gate current pulse and, if not carefully controlled, may result in di/dt failures because the triac switches high-magnitude current under minimum gate drive.

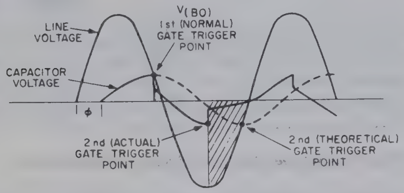


Fig.28 - Charging cycle of capacitor-diac network in Fig. 27 (high hysteresis).

A more effective method of reducing hysteresis is to use a second RC time constant, or a "double-time-constant" circuit such as that shown in Fig. 29. As C_2 supplies the charging voltage for the diac breakover voltage $V_{(BO)}$, the abrupt change is capacitor voltage during diac turn-on is partially restored by capacitor C_1, as shown in Fig. 30. The restoring of the charge on C_2 maintains the original triggering point very closely and results in extended range of the control setting. This triac circuit can be turned on for very low levels of applied voltage and is not prone to "extinguishing" for line-voltage drops.

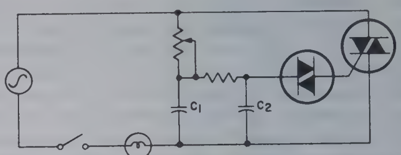


Fig.29 - "Double-time-constant" light-control circuit.

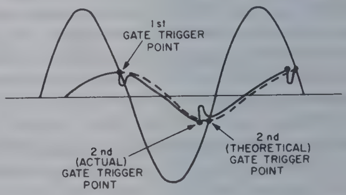


Fig.30 - Charging cycle of capacitor-diac network in Fig. 29 (reduced hysteresis).

Because triac switching from the high-impedance to the low-impedance state can occur in less than one microsecond, the current applied to the load increases from essentially zero to a magnitude limited by the load impedance within the triac switching time. This rapid rise of load current produces radio-frequency interference (RFI) extending into the range of several megahertz. Although this rapid rise does not affect television and FM radio frequencies, it does affect the short-wave and AM radio bands. The level of RFI generated is well below that caused by small ac/dc brush-type motors, but some means of RFI suppression is generally required if the triac phase-control circuit is to be used for any extended period of time in an environment in which RFI generation cannot be tolerated.

A reasonably effective suppression technique is shown in Fig. 31. An inductor is connected in series with the triac control circuit to restrict the current rate of rise, and a filter capacitor is used in parallel with the entire network to bypass high-frequency signals.

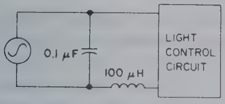


Fig.31 - RFI-suppression network.

The values shown in Fig. 31 are effective in reducing RFI noise for rms load currents up to 6 amperes to such an extent that the effects on short-wave and AM signals are either minimized or considered tolerable. For values above 6 amperes rms, additional suppression can be achieved by use of dual chokes in the ac lines to the triac network. Depending on the circuit performance required, such suppression may or may not be effective and other means of triac control may be required.

An alternate method of providing high-current heating controls is through use of a proportional control circuit using integral-cycle synchronous switching or zero-voltage switching. This approach varies the average power to the load through controlled bursts of full cycles of ac voltage to the load by turning on the triac at the beginning of the zero-voltage crossing. Because the triac turns on near zero current, the sudden current steps associated with phase-control circuits and the RFI generated are minimized. The RCA-CA3059 zero-voltage switch is a monolithic integrated circuit used primarily as a trigger-current generator for control of thyristor turn-on during the zero-voltage transition. This circuit has many features, one of which is a fail-safe circuit which inhibits output pulses in the event that the external sensor is opened or shorted.

Conclusions

This Note has reviewed thyristors from the viewpoints of temperature and voltage conditions, gate trigger characteristics, and effects of SCR's and triacs on circuit performance. The availability of power thyristors gives design engineers greater freedom in achieving circuit simplicity, low cost, and small package assembly than electromechanical or tube counterparts. Technological improvements are far from reaching the saturation level, but are opening new doors for circuit application. The impact of thyristor applications is being felt in normal everyday environments such as residential lamp dimming, TV deflection systems, home appliances, marine ignition, automotive applications, electric heating, comfort controls, and igniters for fuel-fired furnaces. Industrial applications for multiple-horsepower motors, lamp display boards, inverters, relay protection or replacement, radar, sonar, and emergency standby generating systems are now finding widespread acceptance in thyristor controls. The introduction of RCA triacs fully characterized for 400-Hz commutating capability opens the doors to many aircraft support applications which previously were devoid of the advantages offered in solid-state design. It appears that the answer to most power-control applications may be the thyristor.

RCA
Solid State
Division

Thyristors
Application Note
AN-4537

Thyristor Control of Incandescent Traffic-Signal Lamps

by C.P. Knudsen

This Note discusses the use of thyristors in the control of traffic signals. The thyristor most applicable to this application is the triac, which can carry the electrical power required for incandescent traffic-light bulbs, yet can be gated by the low-power signals from electronic control, timers or monitoring computers. In addition, the triac is able to handle the large transient currents that result from cold filament turn-on (inrush) and filament rupture (flashover). Triac operation, stresses on triacs in operation with incandescent lamps, and a number of triac circuits for control of incandescent lamps in traffic signal applications are discussed below.

TRIAC OPERATION

A triac, shown schematically in Fig. 1(a), is a bidirectional triode thyristor. In the absence of a gate signal, the triac blocks both portions of an ac sine wave, but a steady-state or pulsed gate signal will switch it on as in Fig. 1(b). The gate signal can be either positive or negative with respect to main terminal no. 1 (MT1), while MT2 can also be either positive or negative referenced to MT1; the four possible modes of switching are depicted in Table I. For example, when a triac is triggered by connecting a resistor between MT2 and the gate, as shown in Fig. 2, the triac operates in the I+ and III− modes in energizing the ac load. Other thyristor characteristics will be introduced below as needed, while an extensive review of thyristors is available in RCA Application Note AN-4242, "A Review of Thyristor Characteristics and Applications".

SURGE CURRENT THROUGH TRIACS IN INCANDESCENT-BULB OPERATION

The traffic-control circuit designer must be aware of two characteristics of incandescent bulbs: end-of-life filament rupture and cold-filament inrush surge. Both these transient conditions impose a high surge stress on the controlling triac, which without proper circuit design can be destructive.

Flashover

Flashover is a short-duration, extremely high-current surge through the triac that is initiated when a lamp filament ruptures. The rupture is most likely to occur as a result of a termination in bulb life; however it can be caused by a mechanical shock. The mechanism of flashover is initiated by

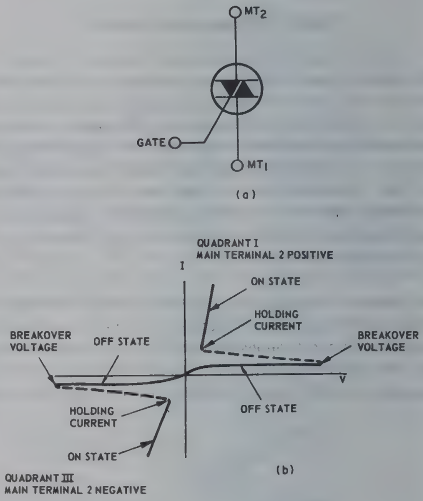


Fig. 1— (a) Schematic symbol, and (b) principal voltage-current characteristic for a triac.

Table I — Four Gate-Trigger Modes For Triac

MODE	MT2	G
I+	+	+
I−	+	−
III+	−	+
III−	−	−

Polarities are referenced to MT1.

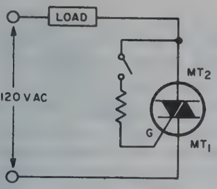


Fig. 2— Example of I+, III- gating of triac.

he gap formed when rupturing occurs. The instantaneous alue of line voltage across the break sets up an electric field hat ionizes the gases in close proximity to the gap. The onized gases, usually argon and nitrogen, provide an lectrical conduction path across the gap, and the resulting urrent heats and ionizes more gases until an arc is formed cross the filament lead-in wires. The arc is maintained as ong as the regenerative heating and ionization continue. Finally, because of either increasing arc length or decreasing c line voltage, or both, the electric field becomes too weak o sustain the arc, and the arc is extinguished.

Fig. 3 shows a flashover current pulse. Its magnitude and luration depend on many factors. The actual peak magniude of the source voltage, the voltage phase at the instant of ilament rupture, and the impedance of the lead wires and ther circuitry (including RFI filters) all affect the duration nd magnitude of the surge. Typical values can be given for he stress of flashover at a load center point. For bulbs of less han 75 watts the duration of the surge can be typically less han 2 milliseconds. For bulbs of 100 to 150 watts the duraion of the surge can be typically less than 4 milliseconds. The nagnitude of surge can vary considerably, with typical peak alues ranging from 80 to 200 amperes when the flashover ccurs near the maximum voltage point. If the flashover ccurs at a zero-voltage crossing, the current surge may be educed as a result of the dependence of the magnitude on the oltage phase at rupture.

Because of the short duration of the flashover current, it s usually difficult to provide circuit fuse protection against lashover. Most incandescent bulbs are provided with a fuse uilt into one of the lead-in wires. This built-in fuse is not 00-per-cent effective against flashover and therefore cannot be depended upon to protect the triac. Fusing of triac circuits is described in more detail in the following discussion of inrush current.

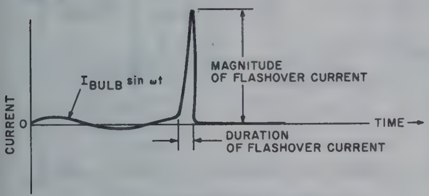


Fig. 3— Flashover current at peak voltage point.

Inrush

In tungsten-filament lamps, the cold filament resistance is approximately 1/18 to 1/12 of the hot filament resistance. The actual currents in a circuit under inrush and steady-state conditions do not vary in these ratios, however, because of the inductance and external limiting resistance of the circuitry, including the lead-in wires to the bulb. Furthermore, it is obvious that the highest inrush current will occur at the peak of the voltage sine wave in a lamp load circuit. If switching occurs at any other phase of the voltage sine wave, the peak current through the bulb is less than "worst case". Typically, the maximum inrush peak current can be ten times as great as the steady-state peak current, while the peak inrush current with zero-voltage switching can be approximately five times as great as the steady-state peak current, as shown in Fig. 4. Thus zero-voltage switching of a lamp effects a soft turn-on that reduces the initial peak of inrush current by half and greatly increases bulb life. This increase of bulb life by zero-voltage switching has been verified by test results; an increase in life of approximately ten times, with a 90 per cent confidence level, has been reported. Thus maintenance costs are reduced and system reliability increased.

Fig. 4 shows how the current in a lamp circuit decreases to the steady-state value. The rate of decrease depends upon the thermal time constant of the tunsten filament. A

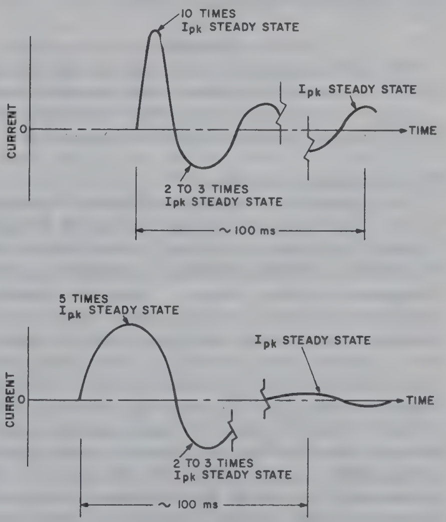


Fig. 4— (a) Inrush current at peak voltage point, and (b) inrush current at zero-voltage point.

100-watt bulb typically might reach steady-state current within 100 milliseconds after turn-on, while a 1000-watt bulb typically requires 200 milliseconds to reach its steady-state current condition.

Flashover and inrush can occur in combination. Because a bulb is exposed to its most severe normal operating stress during inrush, the weakest spot of the filament often ruptures and causes a flashover at turn-on. Most often, switching and flashover occur at some point other than the peak voltage; therefore the resulting peak current is usually within the handling capability of the triac.

Fuses in incandescent-lamp circuits must not blow under the stress of inrush current, yet must blow under flashover current. For low-power bulbs the flashover current is substantially greater than the peak inrush current, and fuse protection is simple. For example, a 100-watt bulb might have a typical flashover current of 100 to 200 amperes and a typical inrush current of 10 amperes. For large-wattage bulbs, however, fusing is difficult. For a 1000-watt bulb, the peak flashover current might still be between 100 and 200 amperes, while the peak inrush current is approximately 120 amperes. Fuses set to blow at 150 amperes peak flashover current of short duration may also blow under the long-duration, slightly-lower-amplitude stress of inrush. As a result, a fusing solution to the problem of triac protection would be marginally reliable. One solution is to use a 40-ampere triac (available in the RCA-2N5443 series), which has a single-cycle surge capability of 300 amperes, to control this 10-ampere load. Here again system reliability would be improved and maintenance costs reduced.

CIRCUITS

With the closely-related transient stresses imposed on a triac by an incandescent-light-bulb circuit having been noted, a number of circuits that help to reduce these stresses on the triac and increase lifetime of the bulb are discussed below.

Zero-Voltage Switching with an IC

An RCA-CA3059 integrated circuit (IC) can be used with a triac to accomplish zero-voltage switching of a load. A functional block diagram of this IC is shown in Fig. 5. The CA3059 is a monolithic, multistage, integrated circuit that incorporates a diode limiter, a threshold detector, a differential amplifier, a Darlington output driver, and other features. A more extensive description of this IC is given in RCA Application Note ICAN-6182, "Features and Applications of RCA Integrated-Circuit Zero-Voltage Switches." The CA3059-and-triac circuit for zero-voltage switching is shown in Fig. 6. When Q1 is off, the IC does not generate pulses to the gate of the triac. When Q1 is biased on, the IC generates gating pulses of approximately 40 milliamperes for 100 microseconds that straddle the zero-voltage crossing points. These pulses trigger the triac on in the I+ and III+ modes at the zero-voltage crossing for the resistive-tungsten-filament bulb and effect the desired result of decreasing inrush current.

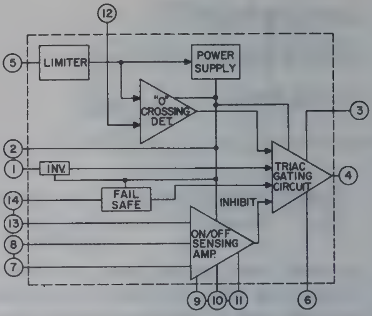
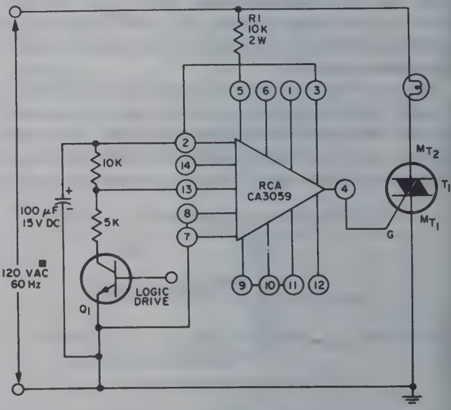


Fig. 5— Functional block diagram of the RCA-CA3059 integrated-circuit zero-voltage switch.

The circuit shown in Fig. 6 has one disadvantage for traffic controls, in which the bulb load is usually grounded and the power circuit ground and the logic ground are common. This arrangement presents a severe problem of interfacing between logic and power circuitry. If the load in Fig. 6 were grounded, terminal No. 4 of the CA3059 would be at line voltage above ground and the substrate (terminal No. 7) at ground potential when the bulb was energized. As a result, the IC would be destroyed. Similar problems are encountered whenever the logic circuitry is directly coupled with the triac power circuit and the load is grounded. However, this problem is eliminated in the discrete-component circuits described below.

Discrete-Component Zero-Voltage Switching

A discrete-component circuit that accomplishes zero-voltage switching of a grounded tungsten filament load is



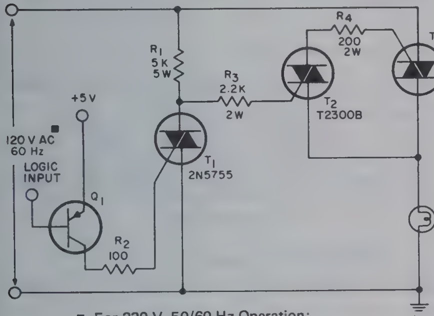
■ For 220-V, 50/60-Hz Operation,
R1=22 K,4 W

Fig. 6— Circuit that uses the CA3059 and a triac to switch a lamp at zero voltage.

shown in Fig. 7. With Q1 on, T1 is on and source voltage is shunted away from the load. With Q1 biased off, T1 is off and T2 is gated on through R1 and R3. When T2 conducts, it connects R4 from gate to MT2 of T3, and thus triggers T3 on in the I+ and III- modes. Because T2 is a sensitive-gate device, it turns on close to the zero-voltage point; therefore, the load is also zero-voltage switched after the initial turn-on. For a typical T2300B device, triggering in the I+ and III- modes results in firing at about 7 volts peak on the line. After T3 is turned on, the triggering circuitry is shorted; therefore, no triggering power is dissipated while the lamp is on.

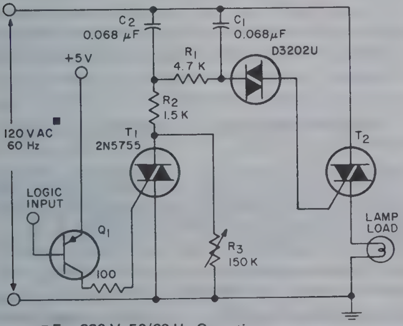
Filament Pre-Heating

Another approach to reducing the inrush current is shown in Fig. 8, where a filament pre-heater function is included in the switching arrangement. In this circuit, when Q1 is off the logic interfacing triac T1 is off. R3, which can be a fixed resistor of approximately 98 kilohms, is set so that T2 is fired for only a small portion of the voltage cycle. This firing is accomplished by the standard double-time-constant lamp-dimmer gate circuitry of T2. The low-conduction-phase firing of the bulb keeps the tungsten filament warm but not hot enough to radiate any readily visible light. When Q1 is turned on, T1 is gated on and R3 is shorted, and the lamp load turns on.



■ For 220-V, 50/60-Hz Operation:
R1=10 K,10 W; R3=4 K,4 W;
T1=2N5756; T2=T2300D

Fig. 7— Discrete-component circuit used to switch a grounded load at zero voltage.



■ For 220-V, 50/60-Hz Operation:
R2=3 K; R3=300 K; T1=2N5756

Fig. 8— A circuit including a filament pre-heat arrangement.

The associated waveforms are shown in Fig. 9. For a 200-watt bulb in the circuit of Fig. 8, the first peak of current through the bulb was 7.5 amperes when the warm up circuit was used and 25 amperes with cold-filament inrush.

These circuits of Figs. 7 and 8 show that triacs can be used to switch power lamp loads and also interface with low-level logic systems. They also show how some of the stresses involved with the switching of incandescent lamps can be reduced. Other switching circuitry for use in traffic controls is discussed below.

OTHER APPLICABLE ON-OFF SWITCHING CIRCUITS

Two other circuits that can be used in the traffic control area are shown in Figs. 10 and 12. These circuits have the advantages of a common ground between logic and power circuitry, grounded bulbs, and isolation between the dc logic and the power circuitry afforded by use of the interfacing logic triacs.

In the positive-logic switching circuit of Fig. 10, logic triac T1 is used to interface between the low level logic and the load triac T2. With T1 gated on, C1 is charged through R1 to the breakover voltage of the diac, at which point T2 and the load are triggered on. The various circuit waveforms are shown in Fig. 11. As Fig. 11(d) shows, there is continuous gate power driving T2 whenever T1 is on and thus the light is on hard.

A variation of this circuit with opposite (negative) logic is shown in Fig. 12. In this circuit, when T1 is triggered on, T2 and the lamp are off. When T1 is off, C1 can charge through R1 and R2 to diac breakover, which discharges C1 into the gate of T2 and energizes the load. The waveforms of this circuit are shown in Fig. 13. Little gate power is dissipated in this circuit because T2 shorts across its gate circuitry when it is on.

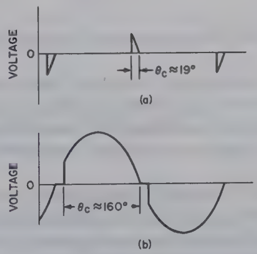
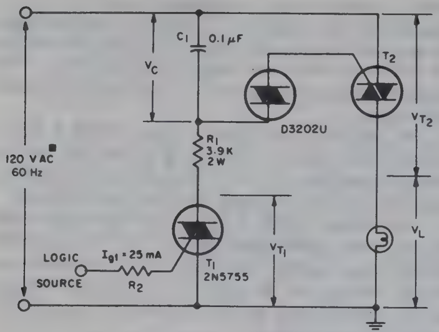


Fig. 9— Waveforms for circuit in Fig. 8: (a) voltage on bulb when Q1 is off; (b) voltage on bulb when Q1 is on.



■ For 220-V, 50/60-Hz Operation:
R1=6 K,3 W; T1=2N5756

Fig. 10— Positive-logic bulb-switching circuit.

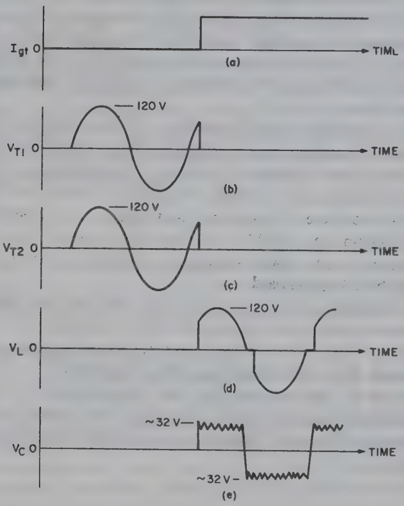
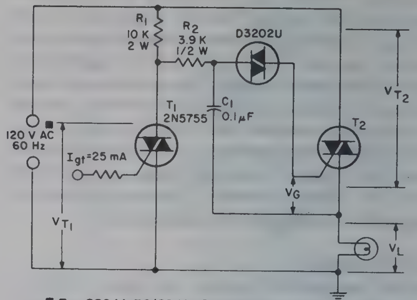


Fig. 11— Waveforms for positive-logic switching.

Both of these circuits are shown with continuous gate drive into triac T1. Logic power could be conserved by use of pulse drive, with no change of power stage operation; however, the logic circuitry would be more complex.

THYRISTOR FLASHER

Thyristors can also be used to advantage in flasher-type traffic-control systems. In these applications, two lights are usually flashed on and off as a warning display. Fig. 14 shows a thyristor circuit that accomplishes this flashing function. As shown, a silicon-controlled-rectifier (SCR) multivibrator functions as the timer and flasher-triggering driver. The drive to the control triac is dc and is alternated between T1 and T2 according to the timing set in the multivibrator. A waveform for the component values shown is displayed in Fig. 15. The timing can be modified by selecting different values for any of the following components: R1, R2, R3, R4, C1, C2. The important features of this circuit are the simple, rugged dc power supply used and the use of SCR's as both timing and memory devices to trigger the triacs. Alternative approaches to the traffic control flasher are given in ICAN-6182, "Features and Applications of RCA Integrated-Circuit Zero-Voltage Switches."



■ For 220-V, 50/60-Hz Operation:
R1=22 K,4 W; T1=2N5756

Fig. 12— Negative-logic bulb-switching circuit.

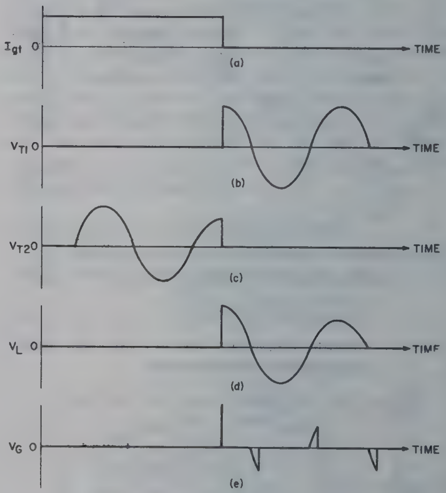
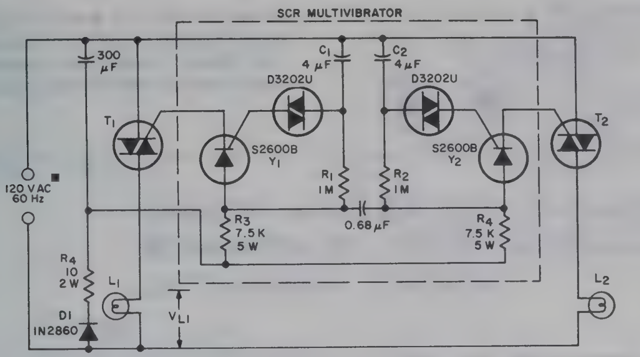


Fig. 13— Waveforms for negative-logic switching.


SCR MULTIVIBRATOR
300 μF
C1 4 μF
C2 4 μF
D3202U
D3202U
T1
T2
S2600B Y1
S2600B Y2
R1 1M
R2 1M
120 VAC 60 Hz
R3 7.5K 5 W
0.68 μF
R4 7.5 K 5 W
R4 10 2 W
L1
L2
D1 1N2860
VL1

■ For 220-V, 50/60-Hz Operation:
R4=22 K,4 W; Y1=Y2=S2600D;
D1=1N2829

Fig. 14— Thyristor flasher.

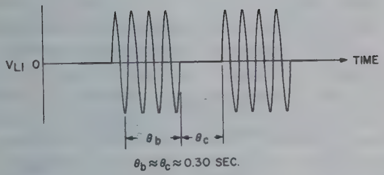


Fig. 15— Timing of thyristor flasher.

AC - DC ISOLATION

In the circuits shown thus far, either a triac or an IC is used to interface between the dc logic and the ac power circuitry. A number of other methods can be used to isolate these stages in a traffic controller. The circuit of Fig. 16 illustrates the use of a reed-type relay. When the relay is activated, the triac is gated in its I+ and III- modes and little power is dissipated in the gate circuit. Fig. 17 shows the use of a light source and photocell combination. Because the photocell is part of a single-time-constant circuit, it must have enough dark resistance to keep the voltage across C1 below 32 volts so that the diac does not switch and discharge the capacitor into the gate of the triac at all times. A pulse transformer can also be used for isolation, as shown in Fig. 18. A 5-kHz signal into the gate turns the triac on at initiation of the pulsing and keeps it on until the oscillator is stopped.

RFI SUPPRESSION

Radio-frequency interference (RFI) that can result from the fast triac switching of high power loads must be considered in traffic control circuits. When an ac load is switched on, as shown in Fig. 19, RFI is generated in the initial wavefront. This steep wavefront contains many harmonics that can be sustained by the circuit Q.

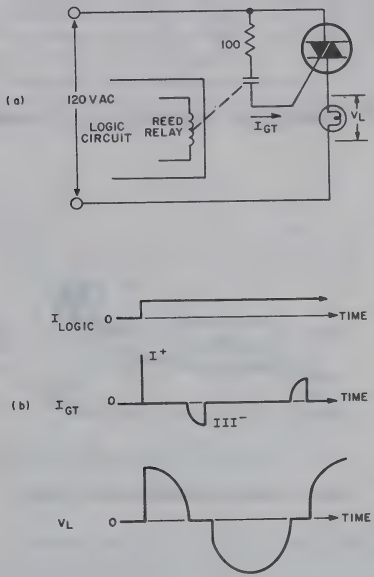

(a)
120 VAC
100
LOGIC CIRCUIT
REED RELAY
IGT
VL
ILOGIC 0
TIME
(b)
IGT
0
I+
III−
TIME
VL
0
TIME

Fig. 16— (a) Circuit, and (b) waveforms of reed-relay gate control.

One method of reducing RFI is zero-voltage switching with resistive loads; thus, the circuits above that utilize the RCA-CA3059 IC inherently include RFI suppression. Circuits that do not use zero-voltage switching require external filters for RFI suppression. A typical filter used in conjunction with ac loads is portrayed in Fig. 20. The effect

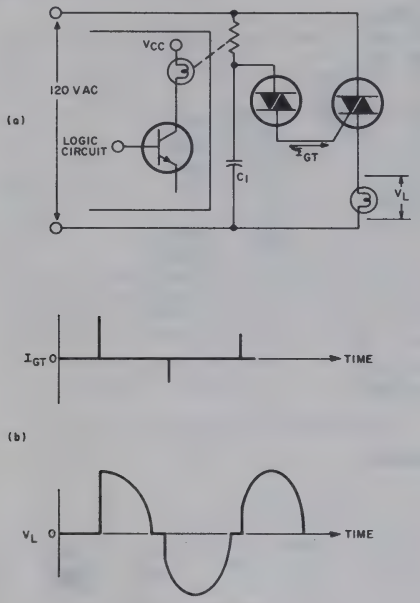

(a)
120 V AC
VCC
LOGIC CIRCUIT
IGT
C1
VL
(b)
IGT 0
TIME
VL 0
TIME

Fig. 17— Photocell gate control: (a) circuit; (b) waveforms.

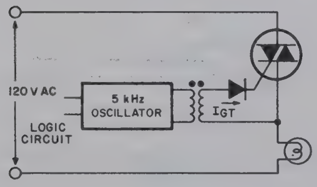

120 V AC
5 kHz OSCILLATOR
IGT
LOGIC CIRCUIT

Fig. 18— Isolation transformer gate control.

of the LC filter is to slow down any fast-rising voltage or current wavefronts that might be propagated down the line and radiated. Other filters are available; each application should include its own filtering design.

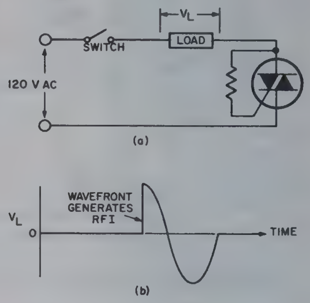

VL
SWITCH
LOAD
120 V AC
(a)
WAVEFRONT GENERATES RFI
VL
0
TIME
(b)

Fig. 19— RFI generation: (a) circuit; (b) waveform.

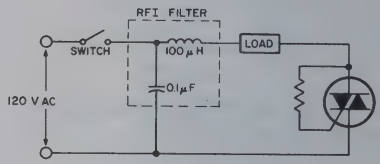

RFI FILTER
SWITCH
100 μH
0.1μF
LOAD
120 V AC

Fig. 20— RFI-suppression filter.

RCA
Solid State
Division

Thyristors
Application Note
AN-4745

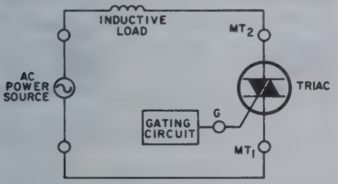
Analysis and Design of Snubber Networks for dv/dt Suppression in Thyristor Circuits

by J. E. Wojslawowicz

When a triac is used to control an inductive load, voltages vith high rates of change (dv/dt) can be generated that can ause a non-gated turn-on of the triac. This false turn-on can ccur if the dv/dt exceeds the critical rate of rise of commutaion voltage of the triac, or if voltage ringing occurs that xceeds the blocking capability of the triac (V_{DROM}). The alse triggering caused by these mechanisms results in a loss f control of power to the load; to assure reliable operation, herefore, it is necessary to provide means to suppress this v/dt stress as it is commonly called. The simplest method of v/dt suppression is the use of a series RC network across the nain terminals of the triac. The design of this network, ommonly called a snubber network, must take into account he peak voltage that can be allowed in the circuit, and the naximum dv/dt stress that the device can withstand. This Note analyzes the RC network design and presents graphs hat allow a designer to select a snubber to fulfill his equirements.

ommutating dv/dt And False Turn-On

Fig. 1 shows a control triac in a typical connection with n ac power source and a load. The triac is a regenerative evice; once it has been turned on, it continues to conduct ntil the principal current drops below a value that just upports the regeneration. This current level is called the olding current of the device. If the gate signal is removed efore the principal current decreases below the holding urrent, the device turns off and regains its blocking apability.



ig. 1— Series connection of a triac, an inductive load, and an ac power source.

Fig. 2 shows the triac principal voltage and current waveforms when the load is resistive. If the gate signal is removed at time t_0, the device continues to conduct until the current attempts to reverse polarity. The device then undergoes a reverse recovery period, and thereafter must support a main terminal voltage of the reverse polarity that is equal to the source voltage. The rate of reapplication of this off-state voltage for a resistive load and a 120-volt 60-Hz source is typically 0.064 volt per microsecond if the stray inductance due to wiring is minimal. This rate of reapplication generally does not cause turn-on of the device.

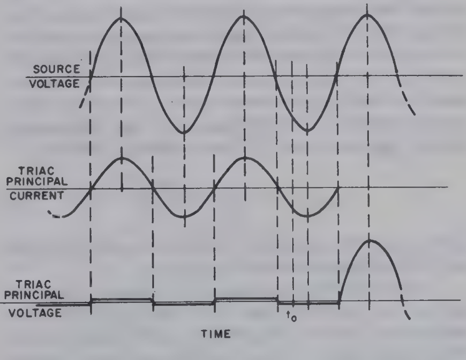


Fig. 2— Principal voltage and current for a triac in operation with a resistive load.

In a circuit with an inductive load the voltage leads the current by some phase angle ϕ as shown in Fig. 3. After the triac turns off it must block the reapplied instantaneous line voltage of the reverse polarity. Because the triac goes from the conducting state to the blocking state in a very short time, this voltage is reapplied very rapidly. The turn-off of the triac causes a rapid decay of current through the inductance, and thus produces an Ldi/dt voltage. This rapidly

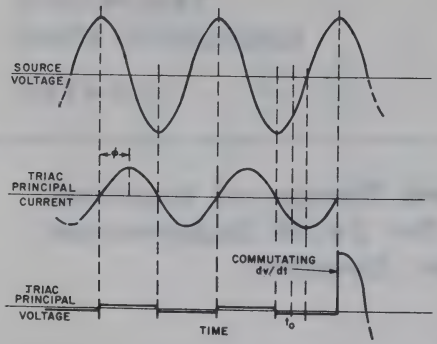


Fig. 3– Principal voltage and current for a triac in operation with an inductive load.

rising off-state voltage stress is impressed across the main terminals of the device and can cause it to turn on. Fig. 4 illustrates this false turn-on.

A triac analog that uses two silicon controlled rectifiers (SCR's) provides a simple understanding of how this dv/dt causes the device to turn on. The inverse parallel SCR analog of the triac is shown in Fig. 5(a), and a two-transistor analog of the SCR is shown in Fig. 5(b). At the end of the half cycle of on-state current conduction, some charge remains in the bases of the equivalent transistors that comprise the conducting SCR. Upon application of the opposite-quadrant off-state voltage, this charge flows as a recovery current. Part of this current flows through the equivalent transistor emitter of the adjacent SCR. In addition, some charge may already exist in the bases of the blocking SCR because of lateral transport of carriers from the previously conducting side. Finally, a capacitive displacement current flows to the reverse-biased middle junction of the blocking SCR; this displacement current, I_{DIS}, can be described by the following equation:

$$I_{DIS} = C_M \frac{dV}{dt} + V \frac{dC_M}{dt} \qquad (1)$$

where C_M is the capacitance of the reverse-biased junction and V is the voltage across that junction.

If the total of the three currents is sufficient to cause the sum of the transistor gains to become unity, the device switches on. The use of the shorted-emitter construction by RCA shunts some of the current away and thus permits a higher dv/dt stress to be placed across the device, but does not eliminate the current completely. The first two current flows are functions of device design and construction, but the displacement current flow can be controlled by use of an RC snubber network that limits the rate of reapplication of off-state voltage.

The snubber network, illustrated in Fig. 6, consists of a resistance R_S and a capacitance C_S placed in series across the main terminals of the device. For some snubber component values and some types of load, excessive ringing can occur in the circuit; this voltage ringing can exceed the blocking capability (V_{DROM}) of the device. Malfunction of the device is then caused by the inability of the triac to block the voltage even though it can withstand the dv/dt stress. An example of voltage ringing is shown in Fig. 7(a). Fig. 7(b) shows the same voltage on an expanded time scale.

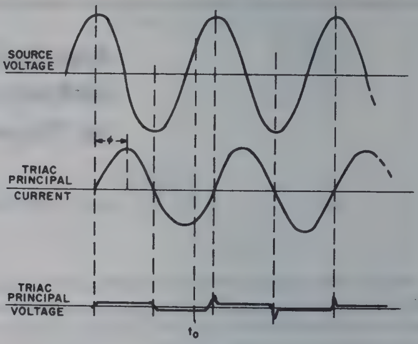


Fig. 4– Principal voltage and current curves showing triac malfunction that results from commutating dv/dt produced by inductive load.

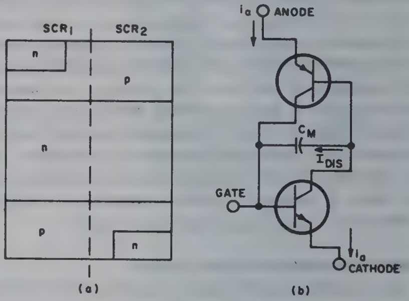


Fig. 5– (a) Two-SCR representation of a triac; (b) two-transistor model of an SCR, with junction capacitance shown.

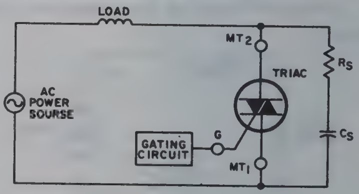
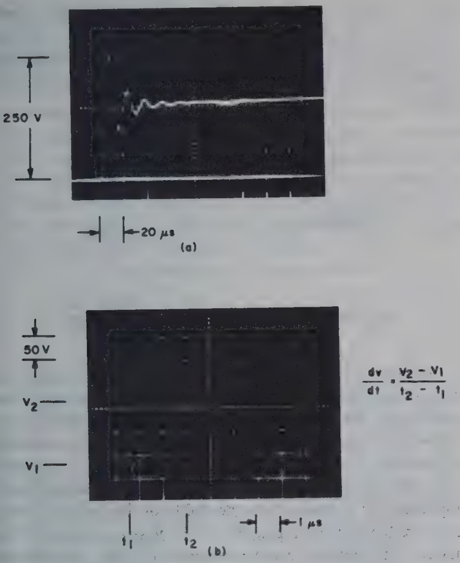


Fig. 6– Triac circuit using a snubber network of R_S and C_S connected across the triac.



g. 7— *(a) Ringing, caused by inductive load, in the principal voltage of triac; (b) principal voltage shown on an expanded scale.*

sic Circuit Analysis

The suppression network must be designed to limit the /dt stress and to have an acceptable voltage overshoot. Fig. shows an equivalent circuit used for analysis, in which the ac has been replaced by an ideal switch. When the triac is the blocking or non-conducting state, represented by the en switch, the circuit is a standard RLC series network iven by an ac voltage source. The following differential uation can be obtained by summing the voltage drops ound the circuit:

$$R_L + R_S)\, i(t) + L\frac{di(t)}{dt} + \frac{q_c(t)}{C_S} = V_M \sin(\omega t + \phi) \qquad (2)$$

which i(t) is the instantaneous current after the switch ens, $q_c(t)$ is the instantaneous charge on the capacitor, V_M the peak line voltage, and ϕ is the phase angle by which e voltage leads the current prior to opening of the switch. fter differentiation and rearrangement, the equation be-mes a standard second-order differential equation with nstant coefficients. With the imposition of the boundary nditions that i(0)=0 and $q_c(0)$=0, the equation for the harge on the capacitor can be stated for the three circuit nditions as follows:

Condition I[1]: $(R_L + R_S)^2 < 4L/C$

$$q_c(t) = \frac{-|V_M|}{\omega |Z|}\cos(\omega t + \phi + \theta)$$
$$+ |Q_t|\, \epsilon^{-\alpha t} \sin(\beta t + \eta) \qquad (3)$$

Condition II[2]: $(R_L + R_S)^2 = 4L/C$

$$q_c(t) = \frac{-|V_M|}{\omega |Z|}\cos(\omega t + \phi + \theta)$$
$$+ \epsilon^{-\alpha t}\ [(1 + \alpha t)\, q_d + i_d t] \qquad (4)$$

Condition III[3]: $(R_L + R_S)^2 > 4L/C$

$$q_c(t) = \frac{-|V_M|}{\omega |Z|}\cos(\omega t + \phi + \theta)$$
$$+ \frac{\epsilon^{-\alpha t}}{\beta'}[(\alpha q_d + i_d t)\sinh \beta' t + \beta' q_d \cosh \beta' t] \qquad (5)$$

The symbols used in these equations are defined as follows:

$$\phi = \tan^{-1}(\omega L/R_L) \qquad (6)$$

$$\theta = -\tan^{-1}\left[\left(\omega L - \frac{1}{\omega C_S}\right)/(R_L + R_S)\right] \qquad (7)$$

$$\alpha = \frac{R_L + R_S}{2L} \qquad (8)$$

$$\beta' = \sqrt{\left(\frac{R_L + R_S}{2L}\right)^2 - \frac{1}{LC_S}} \qquad (9)$$

$$\beta = \sqrt{\frac{1}{LC_S} - \left(\frac{R_L + R_S}{2L}\right)^2} \qquad (10)$$

$$Z = (R_L + R_S) + j\left(\omega L - \frac{1}{\omega C_S}\right) \qquad (11)$$

$$q_d = \frac{|V_M|}{\omega |Z|}\cos(\phi + \theta) + q_c(0) \qquad (12)$$

$$i_d = i(0) - \frac{|V_M|}{|Z|}\sin(\phi + \theta) \qquad (13)$$

$$|Q_t| = \sqrt{\left[\frac{\alpha q_d + i_d}{\beta}\right]^2 + q_d^2} \qquad (14)$$

$$\eta = \tan^{-1}\left(\frac{\beta q_d}{\alpha q_d + i_d}\right) \qquad (15)$$

The voltage across the device is determined by calculating the voltages across the snubber capacitor and resistor from the following fundamental relations:

$$v_{C_S}(t) = \frac{q_c(t)}{C_S} \qquad (16)$$

$$v_{R_S}(t) = R_S\frac{dq_c(t)}{dt} \qquad (17)$$

The sum of these two voltages then represents the instantaneous voltage across the triac. The following equations give the instantaneous voltage for the three circuit conditions:

Condition I: $(R_L + R_S)^2 < 4L/C$

$$v(t) = \frac{-|V_M|}{|Z|}\left[\frac{1}{\omega C_S}\cos(\omega t + \phi + \theta) - R_S \sin(\omega t + \phi + \theta)\right] + |Q_t|\epsilon^{-\alpha t}\left[\frac{1}{C_S}\sin(\beta t + \eta) + \frac{R_S}{\sqrt{LC_S}}\sin(\beta t + \eta + \psi)\right] \quad (18)$$

where ψ is defined by the following expression:

$$\psi = \tan^{-1}\left(\frac{\beta}{-\alpha}\right) \quad (19)$$

Condition II: $(R_L + R_S)^2 = 4L/C$

$$v(t) = \frac{-|V_M|}{|Z|}\left[\frac{1}{\omega C_S}\cos(\omega t + \phi + \theta) - R_S \sin(\omega t + \phi + \theta)\right] + \frac{1}{C_S}[(1 + \alpha t)\, q_d + i_d t]\, \epsilon^{-\alpha t} + R_S[(1 - \alpha t)\, i_d - \alpha^2 t q_d]\, \epsilon^{-\alpha t} \quad (20)$$

Condition III: $(R_L + R_S)^2 > 4L/C$

$$v(t) = \frac{-|V_M|}{|Z|}\left[\frac{1}{\omega C_S}\cos(\omega t + \phi + \theta) - R_S \sin(\omega t + \phi + \theta)\right] + \frac{\epsilon^{-\alpha t}}{\beta' C_s}[(\alpha q_d + i_d)\sinh \beta' t + \beta' q_d \cosh \beta' t] + R_S \epsilon^{-\alpha t}\left[\frac{-\alpha i_d - \frac{1}{LC_S} q_d}{\beta'}\sinh \beta' t + i_d \cosh \beta' t\right] \quad (21)$$

A computer is used to calculate the voltage across the snubber because hand calculation is time-consuming. The magnitude and time of occurrence of the peak voltage are found by numerical analysis, and then the values and times of the voltages at 10 per cent and 63 per cent of peak are calculated. These values are used to compute the dv/dt stress as defined by the following equation:

$$dv/dt = \frac{V_2 - V_1}{t_2 - t_1} \quad (22)$$

where V_1 and t_1 are the voltage and time of the 10-per-cent point and V_2 and t_2 are the voltage and time of the 63-per-cent point. This program therefore allows evaluation of various load and snubber combinations in a matter of minutes.

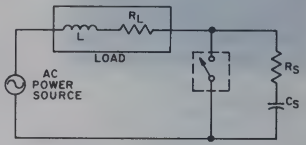


Fig. 8— Equivalent circuit used for analysis.

In general, it is most desirable from a cost standpoint to use a device with the lowest possible V_{DROM} capability. For applications involving the control of a load operating on a 120-volt ac line a device with a V_{DROM} of 200 volts would be desirable; a 400-volt device should be used for operation on a 220-volt line. The use of the lower-voltage device in any application is contingent on the ability of the circuit to limit any possible voltage ringing below the V_{DROM} rating of the device. The snubber can be designed to limit this voltage ringing during the post-commutation period to within this rating. Figs. 9 and 10 show the values of C_S and R_S that limit peak voltage across the triac to specific values. Fig. 9 allows the selection of snubber components that will limit the peak voltage of 200 volts for a zero-power-factor load at the desired dv/dt for an rms line voltage of 120 volts. Fig. 10 shows the components that limit the voltage to 400 volts when the rms line voltage is 220 volts.

Snubber Design Procedure

For use of the graphs, three things must be known: (1) the rms line voltage, (2) the rms load current, and (3) the allowable dv/dt. The following procedure is used to obtain the required snubber components:

(1) Draw a vertical line on the proper voltage graph at the load current.

(2) At the intersection of the vertical line and the dashed line that represents the allowable dv/dt, draw a horizontal line to the right vertical axis. Read the value of R_S from the right vertical axis.

(3) At the intersection of the vertical line and the solid line that represents the allowable dv/dt, draw a horizontal line to the left vertical axis. Read the value of C_S from the left vertical axis.

As an illustration of the above procedure. Fig. 9 is used to find snubber component values that limit the dv/dt stress to 5 volts per microsecond for a 40-ampere rms current in a 120-volt rms line. From Fig. 9, these values are R_s = 340 ohm and C_s = 0.18 microfarad.

As previously stated, these graphs were developed to limit the peak voltage for a zero-power-factor load. For the non-ideal load the graphs are used in the same fashion; a reduction in the peak voltage following commutation and a slight reduction in the dv/dt stress are the only effects introduced by the non-ideal load. The reduction in the peak voltage excursion is caused by the decrease in instantaneous voltage at the time of commutation. As the power factor increases, the phase angle between the voltage and current decreases toward 0°. This decrease in the phase angle shifts the time of commutation in the half-cycle toward the zero-voltage crossing and thus reduces the instantaneous voltage. The reduction in the dv/dt stress is the result of both the reduction in the voltage at commutation and the increasing resistive impedance of the load.

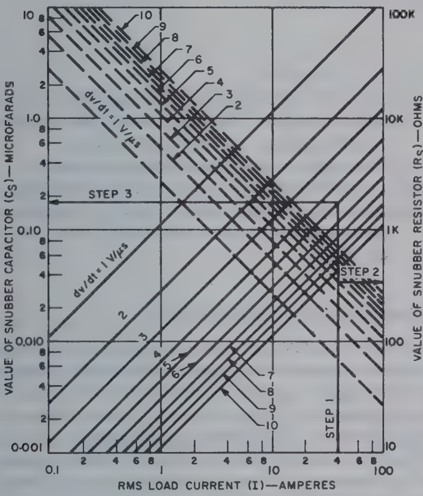


Fig. 9— Design curves for snubber that limits peak voltage to 200 volts for 120-volt ac line and zero power factor.

A numerical example shows how a load that is not purely inductive reduces the peak voltage after commutation. The snubber components for 8 volts per microsecond at an rms current of 22.7 amperes are found from Fig. 9 to be 960 ohms and 0.04 microfarad. If the load is purely inductive, the peak voltage is limited to 200 volts. If the load has the same current rating but a power factor of 0.7, this snubber network limits the peak voltage after commutation to 140 volts. The peak voltage is reduced because the instantaneous line voltage at the time of commutation is only 121 volts. The dv/dt stress is also slightly lower than the 8-volts-per-microsecond value. This example demonstrates that the design graphs of Figs. 9 and 10 can be used for loads having any power factor.

Because the selection of snubber components is dependent on circuit and device characteristics, values obtained may be impractical from a cost or size standpoint. In such a case, a triac with higher dv/dt capability or higher V_{DROM} rating should be used. A higher dv/dt capability allows selection of new snubber components to meet the size and/or cost requirements of the circuit. A higher V_{DROM} rating permits a higher peak voltage excursion that in general will allow selection of a smaller snubber capacitor and smaller resistor.

The circuit analysis described in this Note assumes the effects of the triac to be a minimum. Thus some error is introduced by neglect of the reverse recovery process and the displacement current. The additional current flow tends to increase the instantaneous dv/dt during the first few microseconds following commutation. The over-all effect is to increase slightly the average dv/dt stress across the device. This effect is most noticeable when the snubber capacitance is less than 0.001 microfarad. Selection of a snubber for a lower dv/dt stress limit will generally eliminate this problem.

Because the design of a snubber is contingent on the load, it is almost impossible to simulate and test every possible combination under actual operating conditions. It is advisable to measure the peak amplitude and rate of rise of voltage across the triac after a snubber has been selected.

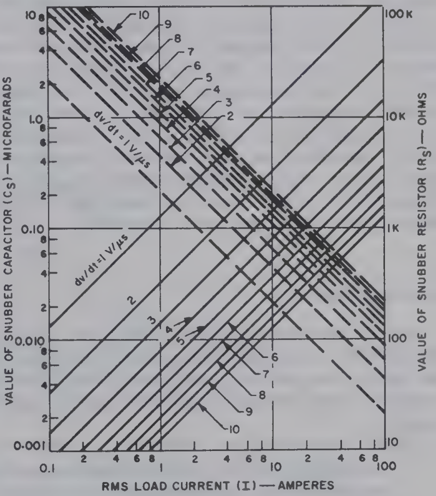


Fig. 10— Design curves for snubber that limits peak voltage to 400 volts for 220-volt ac line and zero power factor.

References

1. Myril B. Reed, Alternating Current Circuit Theory (New York: Harper & Brothers, 1948), pg. 276.
2. Ibid, pg. 284.
3. Ibid, pg. 284.

Triac Power Controls for Three-Phase Systems

by J. Yellin

The growing demand for solid-state switching of ac power in heating controls and other industrial applications has resulted in the increasing use of triac circuits in the control of three-phase power. This Note explains a basic approach to the design of triac control circuits for use in the switching of three-phase power. The basic design rules employed in this approach are outlined, an integrated-circuit zero-voltage switch specifically intended for use in triac triggering is briefly described, and the necessity for and methods of isolation of the dc logic circuitry in power controls for three-phase systems are pointed out. Recommended configurations are then shown for power-control circuits intended for use with both inductive and resistive balanced three-phase loads, and the specific design requirements for each type of loading condition are discussed. (Unbalanced three-phase systems, which have different design requirements, are not covered in this Note.)

Basic Design Rules

In the power-control circuits described in this Note, the RCA-CA3059 integrated-circuit zero-voltage switch is used as the trigger circuit for the power triacs.* The following conditions are also imposed in the design of the triac control circuits:

1. The load should be connected in a three-wire configuration with the triacs placed external to the load; either delta or wye arrangements may be used. Four-wire loads in wye configurations can be handled as three independent single-phase systems. Delta configurations in which a triac is connected within each phase rather than in the incoming lines can also be handled as three independent single-phase systems.
2. Only one logic command signal is available for the control circuits. This signal must be electrically isolated from the three-phase power system.
3. Three separate triac gating signals are required.
4. For operation with resistive loads, the zero-voltage-switching technique should be used to minimize any radio-frequency interference (RFI) that may be generated.

Integrated-Circuit Zero-Voltage Switch

The RCA-CA3059 integrated-circuit zero-voltage switch is intended primarily as a trigger circuit for the control of thyristors and is particularly suited for use in thyristor temperature-control applications. Fig. 1 shows a functional block diagram of the CA3059 integrated-circuit zero-voltage switch. This multistage circuit employs a diode limiter, a threshold detector, a differential amplifier, and a Darlington output driver to provide the basic switching action. The dc supply voltage for these stages is supplied by an internal zener-diode-regulated power supply that has sufficient current capability to drive external circuit elements, such as transistors and other integrated circuits. The trigger pulse developed by this circuit can be applied directly to the gate of an SCR or a triac. A built-in fail-safe circuit inhibits the application of these pulses to the thyristor gate circuit in the event that the external sensor for the integrated-circuit switch should be inadvertently opened or shorted. The CA3059 may be employed as either an on-off type of controller or a proportional controller, depending upon the degree of temperature regulation required.

Fig. 2 shows the schematic diagram for the CA3059 integrated circuit. Any triac that is driven directly from the output terminal of this circuit should be characterized for operation in the I(+) or III(+) triggering modes, i.e., with positive gate current (current flows into the gate for both polarities of the applied ac voltage). The circuit operates directly from a 50-, 60-, or 400-Hz ac line voltage of 120 to 277 volts.

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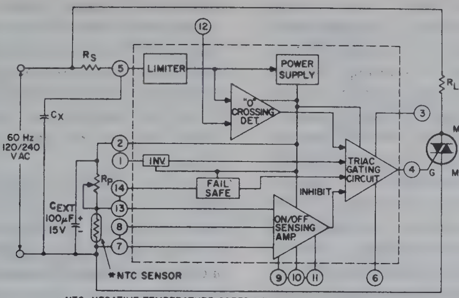
*In addition to the CA3059, the RCA-CA3058 and -CA3079 integrated-circuit zero-voltage switches may also be used for triac triggering in the power-control circuits. All information given on the CA3059 in this Note is, in general, equally applicable to the CA3058 and CA3079.


12
RS
5
LIMITER
POWER SUPPLY
"0" CROSSING DET
CX
60 Hz 120/240 VAC
RL
3
MT2
2
1
INV
TRIAC GATING CIRCUIT
4
G
MT1
RP
14
FAIL SAFE
INHIBIT
CEXT 100µF 15V
13
8
7
ON/OFF SENSING AMP
*NTC SENSOR
9
10
11
6

* NTC = NEGATIVE TEMPERATURE COEFFICIENT

AC Input Voltage (50/60 or 400 Hz) V AC	Input Series Resistor (R_S) k Ω	Dissipation Rating for R_S W
24	2	0.5
120	10	2
208/230	20	4
277	25	5

Fig. 1—Functional block diagram of the CA3059 integrated-circuit zero-voltage switch.

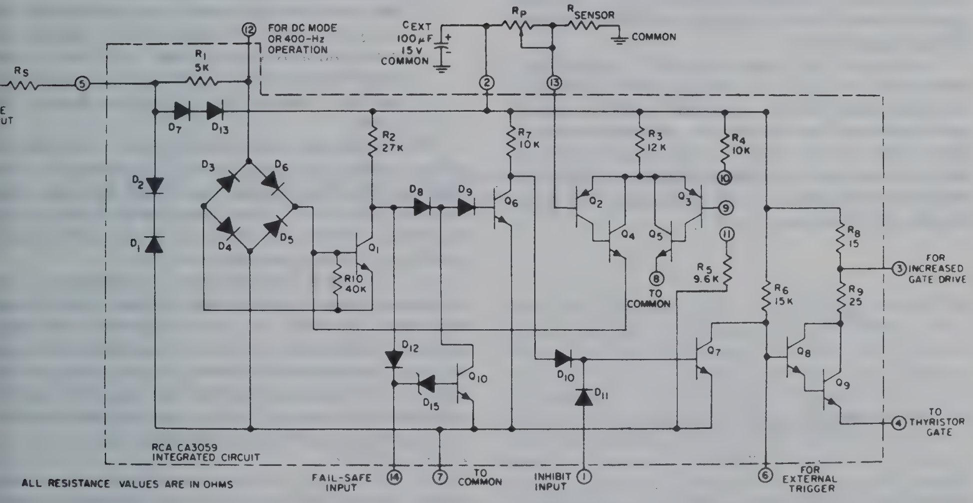

12
FOR DC MODE OR 400-Hz OPERATION
CEXT 100µF 15 V
COMMON
RP
RSENSOR
COMMON
RS
5
E
UT
R1 5K
2
13
D7
D13
D2
D1
D3
D6
D4
D5
R2 27K
D8
D9
Q1
R10 40K
R7 10K
Q6
R3 12K
R4 10K
10
Q2
Q3
9
Q4
Q5
11
8
TO COMMON
R5 9.6K
R8 15
3
FOR INCREASED GATE DRIVE
R9 25
R6 15K
Q7
Q8
Q9
D12
Q10
D15
D10
D11
4
TO THYRISTOR GATE
RCA CA3059 INTEGRATED CIRCUIT
ALL RESISTANCE VALUES ARE IN OHMS
FAIL-SAFE INPUT
14
7
TO COMMON
INHIBIT INPUT
1
6
FOR EXTERNAL TRIGGER

Fig. 2—Circuit diagram for the CA3059 zero-voltage switch.

The diodes D1 and D2 in the CA3059 form a limiter stage that clips the incoming ac line voltage to approximately plus and minus 8 volts. This signal is then applied to the zero-voltage-crossing detector (diodes D3 through D6 and transistor Q1), which generates an output pulse during each passage of the line voltage through zero. The limiter output is also applied to the rectifying diodes D7 and D13 and the external capacitor C_{EXT} that comprise the dc power supply. The power supply provides approximately 6 volts (at terminal 2) as the dc supply to the other stages of the CA3059. The on/off sensing amplifier (transistors Q2 through Q5) is basically a differential comparator. The triac gating circuit contains a driver (transistors Q8 and Q9) for direct triac triggering. The gating circuit is enabled when all the inputs are at a high voltage, i.e., the line voltage must be approximately zero volts, the sensing-amplifier output must be "high", the external voltage to terminal 1 must be a logical "1", and the output of the fail-safe circuit must be "high".

Fig. 3 shows the position and width of the pulses supplied to the gate of a thyristor with respect to the incoming ac line voltage. The CA3059 can supply sufficient gate voltage and current to trigger most RCA thyristors at ambient temperatures of 25°C. However, under worst-case conditions (i.e., at low ambient-temperature extremes and maximum trigger requirements), selection of the higher-current thyristors may be necessary for particular applications. (The RCA technical bulletin File No. 406 lists triacs designed for use with the integrated-circuit zero-voltage switch as the triggering circuit. Detailed information on the operating characteristics and capabilities of this integrated circuit are given in RCA technical bulletin File No. 490, RCA application note ICAN-6182, and the *RCA Linear Integrated Circuits* Manual, IC-42.)

As shown in Fig. 1, when terminal 13 is connected to terminal 14, the fail-safe circuit of the CA3059 is operable. If the sensor should then be accidentally opened or shorted, power is removed from the load (i.e., the triac is turned off). The internal fail-safe circuit functions properly, however, only when the ratio of the sensor impedance at 25°C, if a thermistor is the sensor, to the impedance of the potentiometer. R_p is less than 4 to 1.

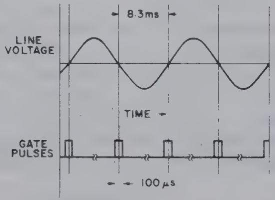


Fig. 3– Timing relationship between the output pulses of the CA3059 and the ac line voltage (pulse duration shown is a typical value for operation from a 120-volt 60-Hz line voltage).

Isolation of DC Logic Circuitry

Isolation of the dc logic circuitry* from the ac line, the triac, and the load circuit is often desirable even in many single-phase power-control applications. In control circuits for polyphase power systems, however, this type of isolation is essential, because the common point of the dc logic circuitry cannot be referenced to a common line in all phases.

In the three-phase circuits described in this Note, photo-optic techniques (i.e., photo-coupled isolators) are used to provide the electrical isolation of the dc logic command signal from the ac circuits and the load. The photo-coupled isolators consist of an infrared light-emitting diode aimed at a silicon photo transistor, coupled in a common package. The light-emitting diode is the input section, and the photo transistor is the output section. The two components provide a voltage isolation typically of 1500 volts. Other isolation techniques, such as pulse transformers, magnetoresistors, or reed relays, can also be used with some circuit modifications.

Resistive Loads

Fig. 4 illustrates the basic phase relationships of a balanced three-phase resistive load, such as may be used in heater applications, in which the application of load power is controlled by zero-voltage switching. The following conditions are inherent in this type of application:

1. The phases are 120 degrees apart; consequently, all three phases cannot be switched on simultaneously at zero voltage.
2. A single phase of a wye configuration type of three-wire system cannot be turned on.
3. Two phases must be turned on for initial starting of the system. These two phases form a single-phase circuit which is out of phase with both of its component phases. The single-phase circuit leads one phase by 30 degrees and lags the other phase by 30 degrees.

These conditions indicate that in order to maintain a system in which no appreciable RFI is generated by the switching action from initial starting through the steady-state operating condition, the system must first be turned on, by zero-voltage switching, as a single-phase circuit and then must revert to synchronous three-phase operation.

Fig. 5 shows a simplified circuit configuration of a three-phase heater control that employs zero-voltage synchronous switching in the steady-state operating condition, with random starting. In this system, the logic command to turn on the system is given when heat is required, and the command to turn off the system is given when heat is not required. Time proportioning heat control is also possible through the use of logic commands.

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*The dc logic circuitry provides the low-level electrical signal that dictates the state of the load. For temperature controls, the dc logic circuitry includes a temperature sensor for feedback. The RCA integrated-circuit zero-voltage switch, when operated in the dc mode with some additional circuitry, can replace the dc logic circuitry for temperature controls.

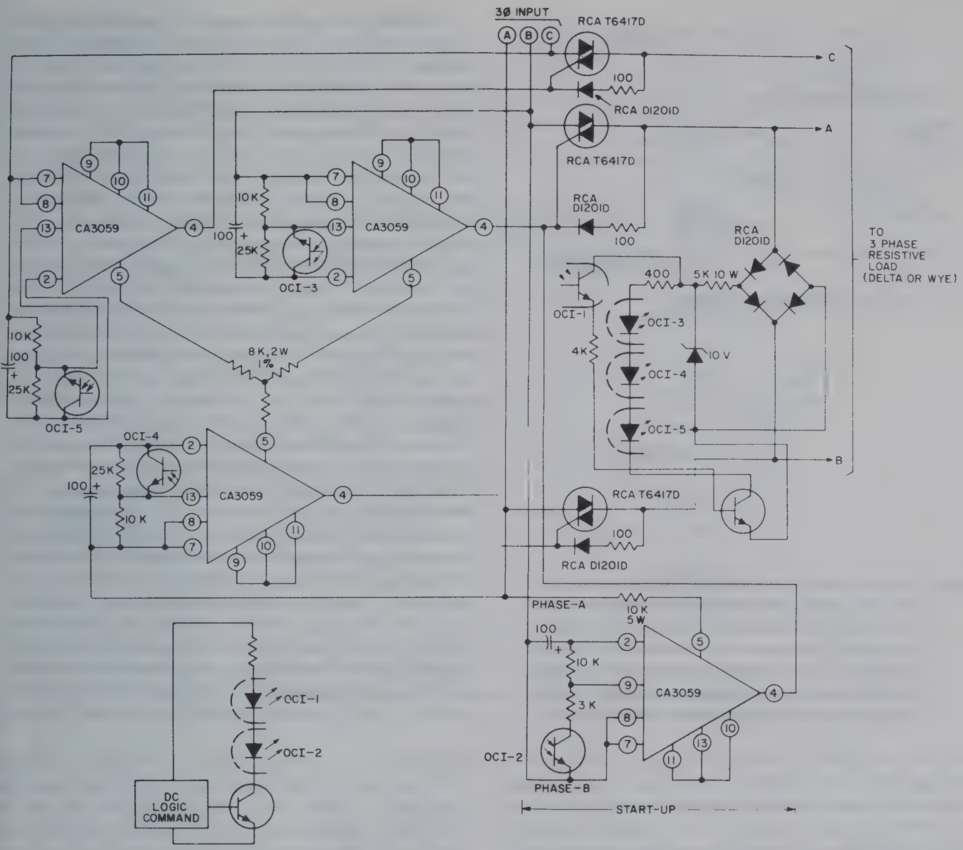
3Ø INPUT
A
B
C
RCA T6417D
100
RCA D1201D
RCA T6417D
RCA D1201D
100
RCA D1201D
TO 3 PHASE RESISTIVE LOAD (DELTA OR WYE)
CA3059
CA3059
CA3059
CA3059
10K
100
25K
OCI-3
OCI-5
OCI-4
OCI-1
OCI-2
8 K, 2W 1%
400
5K 10 W
4K
10 V
PHASE-A
10 K 5 W
10 K
3 K
PHASE-B
START-UP
DC LOGIC COMMAND

Fig. 6—Three-phase power control that employs zero-voltage synchronous switching both for steady-state operation and for starting.

as start-up is accomplished, the three photo-coupled isolators OCI3, OCI4, and OCI5 take control, and three-phase synchronization begins. When the "logic command" is turned off, all control is ended, and the triacs automatically turn off vhen the sine-wave current decreases to zero. Once the first phase turns off, the other two will turn off simultaneously, 90° later, as a single-phase line-to-line circuit, as is apparent rom Fig. 4.

nductive Loads

For inductive loads, zero-voltage turn-on is not generally required because the inductive current cannot increase instantaneously; therefore, the amount of RFI generated is usually negligible. Also, because of the lagging nature of the inductive current, the triacs cannot be pulse-fired at zero voltage. There are several ways in which the CA3059 may be interfaced to a triac for inductive-load applications. The most direct approach is to use the CA3059 in the dc mode, i.e., to provide a continuous dc output instead of pulses at points of zero-voltage crossing. This mode of operation is accomplished by connection of terminal 12 to terminal 7, as shown in Fig. 7. The output of the CA3059 should also be limited to approximately 5 milliamperes in the dc mode by the 750-ohm series resistor. Use of a triac such as the RCA T2301D is recommended for this application. Terminal 3 is connected to terminal 2 to limit the steady-state power

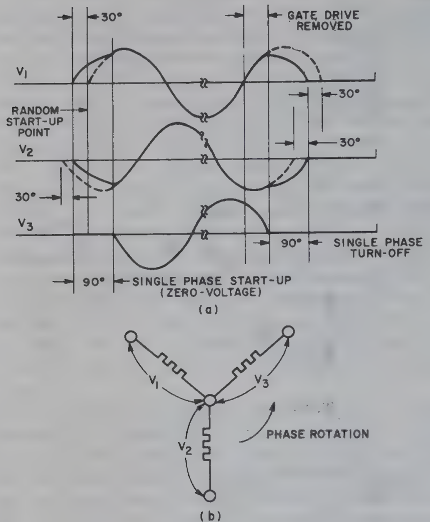
30°
GATE DRIVE REMOVED
V_1
30°
RANDOM START-UP POINT
30°
V_2
30°
V_3
90°
SINGLE PHASE TURN-OFF
90°
SINGLE PHASE START-UP (ZERO-VOLTAGE)
(a)
V_1
V_3
V_2
PHASE ROTATION
(b)

Fig. 4– Voltage phase relationship for a three-phase resistive load when the application of load power is controlled by zero-voltage switching: (a) voltage waveforms, (b) load-circuit orientation of voltages. (The dashed lines indicate the normal relationship of the phases under steady-state conditions. The deviation at start-up and turn-off should be noted.)

The three photo-coupled inputs to the three CA3059 circuits change state simultaneously in response to a "logic command". The CA3059 circuits then provide a positive pulse, approximately 100 microseconds in duration, only at a zero-voltage crossing relative to their particular phase. A balanced three-phase sensing circuit is set up with the three CA3059 circuits each connected to a particular phase on their common side (terminal 7) and referenced at their high side (terminal 5), through the current-limiting resistors R4, R5, and R6, to an established artificial neutral point. This artificial neutral point is electrically equivalent to the inaccessible neutral point of the wye type of three-wire load and, therefore, is used to establish the desired phase relationships. The same artificial neutral point is also used to establish the proper phase relationships for a delta type of three-wire load. Because only one triac is pulsed on at a time, the diodes (D1, D2, and D3) are necessary to trigger the opposite-polarity triac, and, in this way, to assure initial latching-on of the system. The three resistors (R1, R2, and R3) are used for current limiting of the gate drive when the opposite-polarity triac is triggered "on" by the line voltage.

In critical applications that require suppression of all generated RFI, the circuit shown in Fig. 6 may be used. In addition to synchronous steady-state operating conditions. this circuit also incorporates a zero-voltage starting circuit. The start-up condition is zero-voltage synchronized to a single-phase, 2-wire, line-to-line circuit, comprised of phases A and B. The logic command engages the single-phase "start-up" CA3059 and three-phase photo-coupled isolators OCI3, OCI4, OCI5 through the photo-coupled isolators OCI1 and OCI2. The single-phase CA3059, which is synchronized to phases A and B, starts the system at zero voltage. As soon

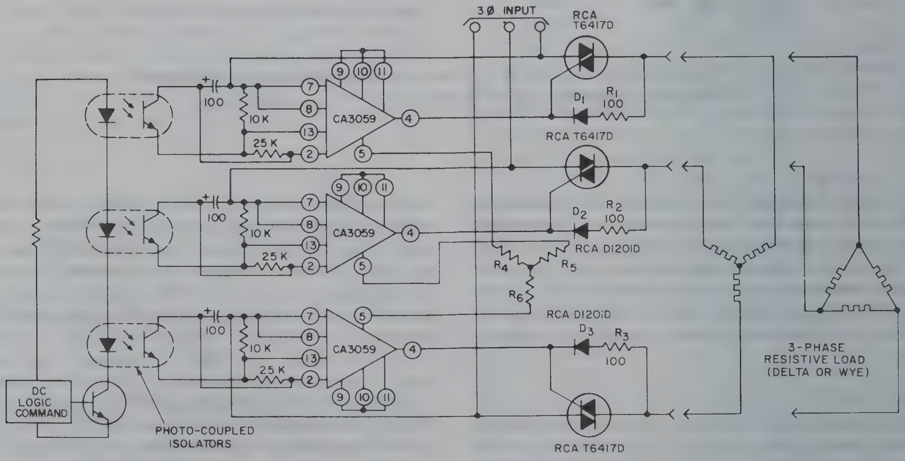
3Ø INPUT
RCA T6417D
100
10 K
25 K
CA3059
7
8
13
2
9
10
11
4
5
D_1
R_1 100
RCA T6417D
D_2
R_2 100
RCA D1201D
R_4
R_5
R_6
RCA D1201D
D_3
R_3 100
RCA T6417D
3-PHASE RESISTIVE LOAD (DELTA OR WYE)
DC LOGIC COMMAND
PHOTO-COUPLED ISOLATORS

Fig. 5—Simplified diagram of a three-phase heater control that employs zero-voltage synchronous switching in the steady-state operating conditions.

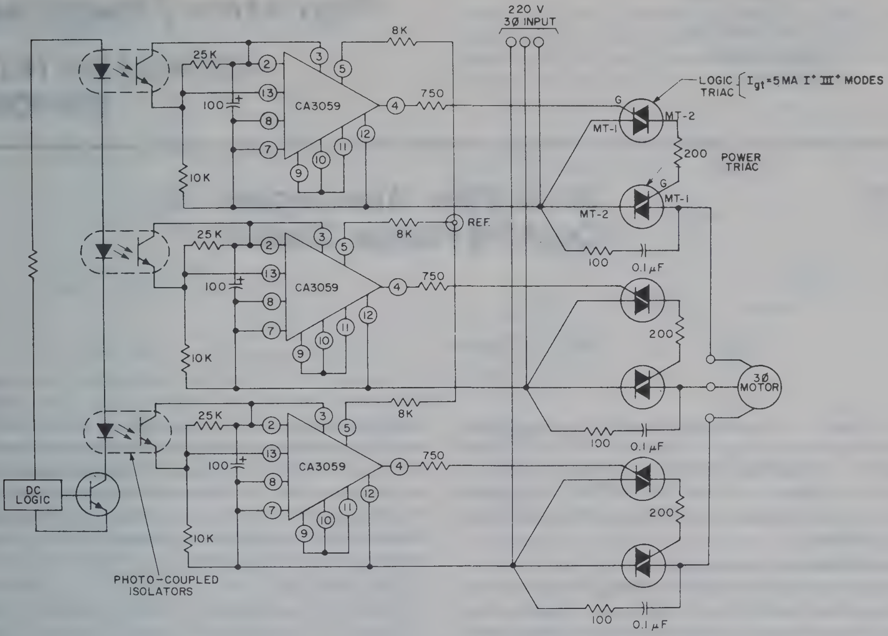
220 V
30 INPUT
8K
25K
2
3
5
13
100
CA3059
4
750
8
7
12
11
10
9
10K
REF.
LOGIC TRIAC
I_{gt}=5MA I+ III+ MODES
G
MT-1
MT-2
200
POWER TRIAC
100
0.1 µF
30 MOTOR
DC LOGIC
PHOTO-COUPLED ISOLATORS

Fig. 7—Triac three-phase control circuit for an inductive load, i.e., three-phase motor.

dissipation within the CA3059. For most three-phase inductive load applications, the current-handling capability of the T2301D triac (2.5 amperes) is not sufficient. Therefore, the T2301D is used as a trigger triac to turn on any other currently available power triac that may be used. The trigger triac is used only to provide trigger pulses to the gate of the power triac (one pulse per half cycle); the power dissipation in this device, therefore, will be minimal.

Simplified circuits using pulse transformers and reed relays will also work quite satisfactorily in this type of application. The RC networks across the three power triacs are used for suppression of the commutating dv/dt when the circuit operates into inductive loads. (A detailed explanation of commutating dv/dt is provided in the basic discussion of thyristors in the *RCA Solid-State Power Circuits Designer's Handbook*, SP-52.)

RCA
Solid State
Division

Thyristors / Rectifiers

Application Note
AN-6096

Solid-State Approaches to Cooking-Range Control

by C. P. Knudsen

As a result of decreasing semiconductor costs, advanced system-cost analysis by appliance manufacturers, and increased consumer consciousness, various solid-state range-control designs can be applied to today's market. This Note presents various solid-state design approaches available to the range-control designer.

Design and Function Considerations

The primary areas of range control design to be considered are the various heating elements: the oven, broiler, and top burners. The most popular method of control of these units is by switching relays or "infinite-switch"-type heat-sensitive switches. Such controls generate radio-frequency interference, RFI, and can have limited life with respect to switching cycles because of contact failures. In addition, the nest of wiring usually needed to interconnect the incoming power line and the various independent loads results in substantial labor costs and possible substantial in-line reworking of ranges to accommodate design changes or failures. Calibration of these controls is generally cumbersome and time consuming because multiple settings are usually involved. However, from the standpoint of parts cost, the control is acceptable.

Semiconductor costs have been decreasing, and are approaching electromechanical-component costs; however, to justify the use of solid-state controls, cost factors other than actual parts costs must be considered. The reliability and the ease of handling of solid-state controls add to their dependable operation and desirability. Dependability can be measured in fewer in-line design corrections and possibly fewer calibrations, and, in turn, lower manufacturing costs. Lower manufacturing costs coupled with the ease of handling of printed circuit boards, which eliminate the nest of wiring, represent a further over-all system-cost reduction.

Other advantages of solid-state-control designs are manifest in their ability to accept design change or add-on designs to satisfy a customer's desire for improved products. For example, the self-cleaning feature is easily incorporated in the various oven controls; this feature is discussed in detail below.

Before any particular design approaches are discussed, a review of some of the characteristics of the devices used is recommended. Because of the unusually high ambient temperatures that can be encountered in various areas of the range, caution must be used in locating the semiconductors, particularly the power devices. Areas on the range that allow for the mounting of these devices and/or their heat sinks should be determined by the appliance manufacturer according to temperature profiles of his enclosure.

Top-Burner Controls

As an introductory method of control, a retrofit approach to the top-burner design where "infinite" control is used is examined. A single-time-constant phase-control circuit is used on each burner as the infinite control. Fig. 1 shows the schematic diagram of the circuit; Fig. 2 shows the various waveforms for the circuit. Because each heater-control circuit is identical, an examination of one, B_1, is sufficient for an understanding of all of the circuits. Potentiometer P_1, resistor R_1, and capacitor C_1 form a 60-Hz voltage divider in which high values of resistance for P_1 limit the peak voltage swing on C_1. The diac, which is a three-layer, p-n-p device, exhibits a high impedance until a peak voltage of approximately 32 volts is applied across it. At this time it displays a negative resistance.

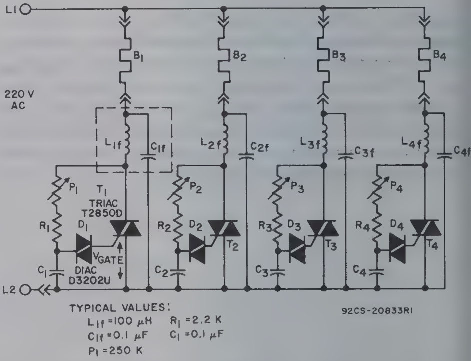

Fig. 1— Schematic diagram of retrofit-type top-burner control.

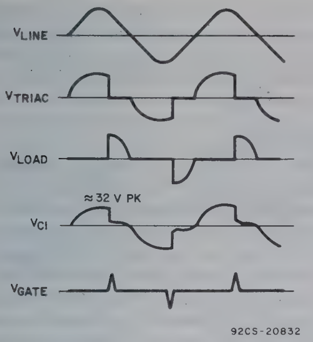

Fig. 2— Waveforms for the circuit of Fig. 1.

Therefore, if the potentiometer is set to allow capacitor C_1 to charge up to 32 volts peak, the capacitor discharges through the diac into the gate of the triac and turns the triac on to its low-impedance state. This action is repeated every half cycle. L_{1f} and C_{1f} are included to suppress the RFI generated by the switching wavefront of the triac.

This type of circuit is a retrofit design, but it has several disadvantages. These disadvantages include cost, the need for RFI filtering (a substantial part of the total cost), and the need for considerable hand wiring, as the bulky discrete components do not warrant printed-circuit-board mounting. However, infinite-switch-type control of the burners is accomplished, and the feasibility of solid-state device use in the control design is demonstrated.

Oven/Broiler Controls

Fig. 1 shows that the triac can be used to switch the burner elements without arcing or contact bounce, but the resulting "clean" waveform, Fig. 2, still has a high-frequency content in the AM broadcast band. To suppress this nuisance, a costly RFI filter must be incorporated in the design. The triac can still be utilized, however, by using another circuit approach, zero-voltage switching, ZVS, that can switch the heavy resistive loads with minimized RFI generation.

Zero-voltage switching is demonstrated in the oven control circuit shown in Fig. 3. In this circuit, a sensor element is included in the oven to provide a closed-loop system for accurate control of the oven temperature. The RCA CA3059[1,2] is used to accomplish the zero-voltage logic switching; the functional block diagram for the CA3059 is shown in Fig. 4.*

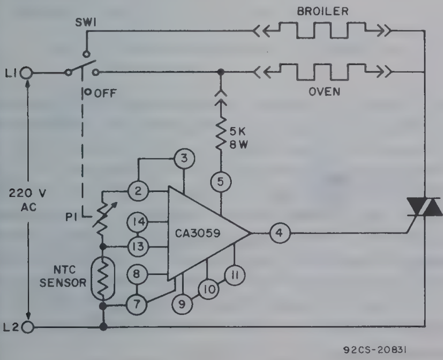

Fig. 3— Schematic diagram of basic oven control.

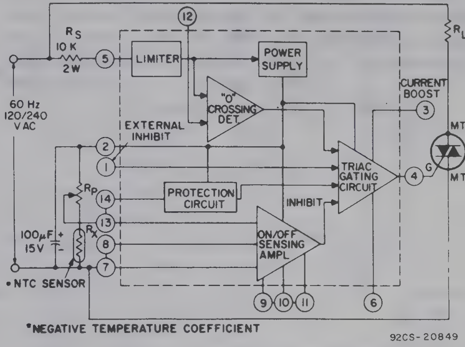

Fig. 4— Functional block diagram of CA3059 integrated-circuit zero-voltage switch.

The limiter stage of the CA3059 clips the incoming ac line voltage to approximately ±8 volts. This signal is then applied to the zero-voltage-crossing detector, which generates an output pulse during each passage of the line voltage through zero. The limiter output is also applied to a rectifying diode and an external capacitor that comprise the dc power supply. The power supply provides approximately 6 volts, as the V_{CC} supply, to the other stages of the CA3059. The on/off sensing amplifier is basically a differential comparator. The triac gating circuit contains a driver for direct triac triggering. The gating circuit is enabled when all the inputs are at a high voltage; i.e., the line voltage must be approximately zero volts, the sensing-amplifier output must be high, the external voltage to terminal 1 must be a logical 1, and the output of the fail-safe circuit must be high.

Fig. 5 shows the circuit diagram of the CA3059. The zero-voltage threshold detector consists of diodes D_3, D_4, D_5, and D_6, and transistor Q_1. The differential amplifier consists of transistor-pairs Q_2–Q_4 and Q_3–Q_5. Transistors Q_1, Q_6, Q_7, Q_8, and Q_9 comprise the triac gating circuit and driver stage. Diode D_{12}, zener-diode D_{15}, and transistor Q_{10} constitute the fail-safe circuit. The power supply consists of diodes D_7 and D_{13} and an external resistor and capacitor connected to terminals 5 and 2, respectively, and to ground through pin 7. If transistor pair Q_2–Q_4 and transistor Q_1 are turned off, an output appears at terminal 4. Transistor Q_1 is in the off state if the incoming line voltage is less than approximately the sum of the voltage drops across three silicon diodes (2.1 volts) for either the positive or negative excursion of the line voltage. Transistor pair Q_2–Q_4 is off if the voltage across the sensor, connected from terminals 13 to 7, exceeds the reference voltage from 9 to 7. If either of these conditions is not satisfied, pulses are not supplied to terminal 4. Fail-safe operation requires that terminal 13 be connected to terminal 14. The addition of

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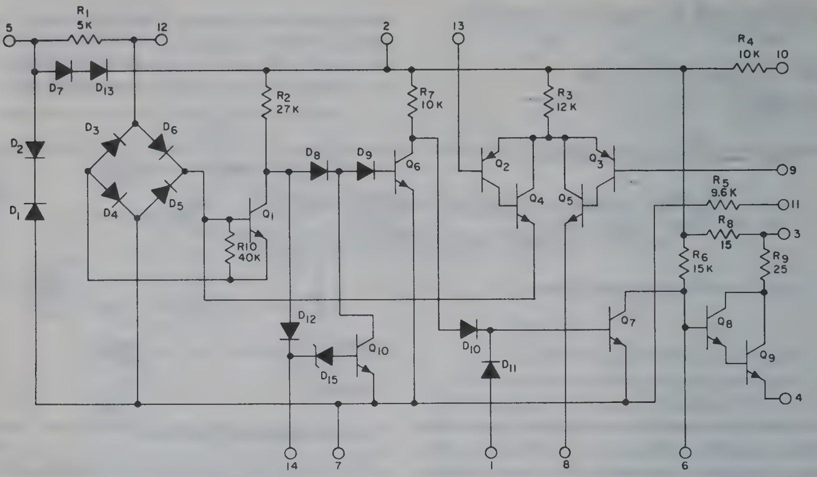
* The CA3079 can be interchanged with the CA3059 in many applications, as demonstrated in this Note.

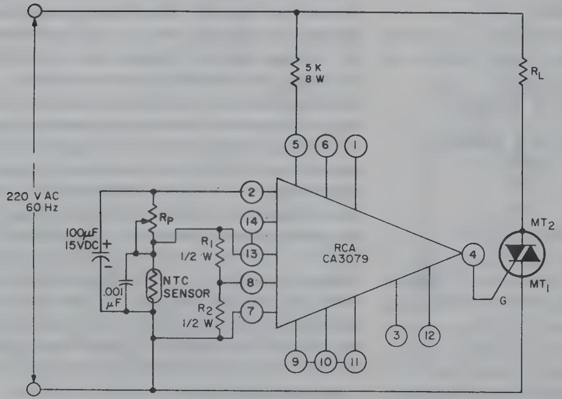

R1
5K
5
12
2
13
R4
10K
10
D7
D13
R2
27K
R7
10K
R3
12K
D3
D6
D2
D1
D4
D5
D8
D9
Q6
Q2
Q3
Q4
Q5
Q1
R10
40K
R5
9.6K
9
11
R8
15
3
R6
15K
R9
25
D12
Q10
D15
D10
D11
Q7
Q8
Q9
4
14
7
1
8
6
92CM-15738R1

ALL RESISTANCE VALUES ARE IN OHMS

Fig. 5— Schematic diagram of CA3059 zero-voltage switch.

hysteresis and the elimination of half-cycling can be achieved by a resistive voltage divider connected from terminals 13 to 8 and from 8 to 7.

As shown in Fig. 3, the temperature of the oven can be adjusted by means of P_1, which acts, along with the sensor, as a voltage divider at terminal 13. The voltage at terminal 13 is compared to the fixed bias at terminal 9 which is set by internal resistors R_4 and R_5. When the oven is cold and the resistance of the sensor is high, Q_2 and Q_4 are off, a pulse of gate current is applied to the triac, and heat is applied to the oven. Conversely, as the desired temperature is reached, the bias at terminal 13 turns the triac off. The closed-loop feature then cycles the oven element on and off to maintain the desired temperature to approximately ±2°C of the set value. Also, as has been noted, external resistors between terminals 13 and 8, and 7 and 8, can be used to vary this temperature and provide hysteresis. In Fig. 6, a circuit that provides approximately 10-per-cent hysteresis is demonstrated.


5K
8W
RL
5
6
1
2
14
13
8
7
Rp
R1
1/2 W
NTC
SENSOR
R2
1/2 W
100µF
15VDC
.001
µF
220 V AC
60 Hz
RCA
CA3079
4
MT2
MT1
G
3
12
9
10
11

THERMISTOR→

NTC	R_1	R_2
5 K	12 K	12 K
12 K	68 K	12 K
100 K	200 K	18 K

Fig. 6— CA3079 on-off controller with hysteresis.

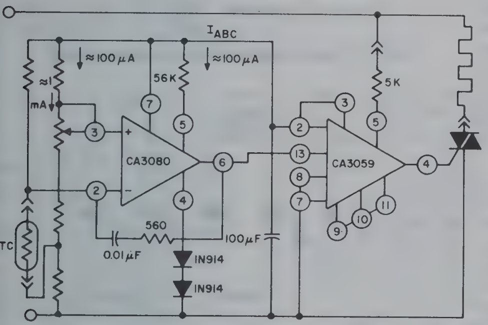
92CS-20841

In addition to allowing the selection of a hysteresis value, the flexibility of the control circuit permits incorporation of other features. A PTC sensor is readily used by interchanging terminals 9 and 13 of Fig. 3 and substituting the PTC for the NTC sensor. Note that in both cases the sensor element is directly returned to the system ground or common, as is often desired. Terminals 9, 10, and 11, Fig. 3, can be connected by external resistors to provide for a variety of biasing, e.g., to match a lower-resistance sensor for which the switching point voltage has been reduced to maintain the same sensor current.

To accommodate the self-cleaning feature, external switching, which enables both broiler and oven units to be paralleled, can easily be incorporated in the design. Of course, the potentiometer must be capable of a setting such that the sensor, which must be characterized for the high, self-clean temperature, can monitor and establish control of the high-temperature, self-clean mode. The ease with which this self-clean mode can be added makes the over-all solid-state system cost-competitive with electromechanical systems of comparable capability. In addition, the system incorporates solid-state reliability while being neater, more easily calibrated, and containing less-costly system wiring.

Low-Resistance Sensor

The circuit of Fig. 3 performs well with sensor values in the 5- to 10-kilohm range, and is used widely in home comfort controls. Although PTC sensors rated at 5 kilohms are available, the existing sensors in ovens are usually of a much lower value. The circuit depicted in Fig. 7 is offered to accommodate these inexpensive metal-wound sensors. A schematic diagram of the RCA CA3080, the operational transconductance amplifier used in Fig. 7, is shown in Fig. 8.[3] With an amplifier bias current, I_{ABC}, of 100 microamperes, a forward transconductance of 2 millimhos is achieved in this configuration. The CA3080 switches when the voltage at terminal 2 exceeds the voltage at terminal 3. This action allows the sink current, I_S, to flow from terminal 13 of the CA3059 (the input impedance to terminal 13 of the CA3059 is approximately 50 kilohms); gate pulses are no longer applied to the triac because Q_2 of the CA3059 is on. Hence, if the PTC sensor is cold, i.e., in the low resistance state, the load is energized. When the temperature of the PTC sensor increases to the desired temperature, the sensor enters the high resistance state, the voltage on terminal 2 becomes greater than that on terminal 3, and the triac switches the load off. Further cycling depends on the voltage across the sensor. Hence, very low values of sensor and potentiometer resistance can be used in conjunction with the CA3059 power supply without causing adverse loading effects and impairing system performance.



92CS-20842

Fig. 7– Schematic diagram of circuit for use with low-resistance sensor.

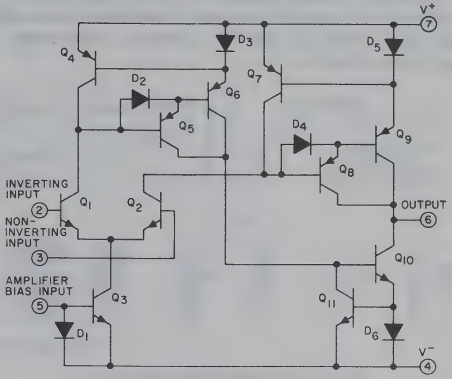
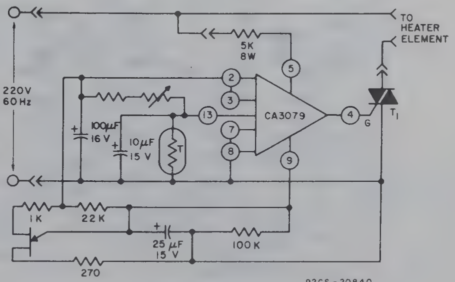


Fig. 8– Schematic diagram of the CA3080. 92CS-17587

Proportional Zero-Voltage Switching

Zero-voltage switching control can be extended to applications in which it is desirable to have constant control of the temperature and a minimization of system hysteresis. A closed-loop top-burner control in which the temperature of the cooking utensil is sensed and maintained at a particular value is a good example of such an application; the circuit for this control is shown in Fig. 9. In the circuit, a unijunction oscillator is outboarded from the basic control by means of the internal power supply of the RCA CA3079. The output of this ramp generator is applied to terminal 9 of the CA3079 and establishes a varied reference to the differential amplifier.



92CS-20840

Fig. 9– Schematic diagram of proportional zero-voltage-switching control.

Therefore, gate pulses are applied to the triac whenever the voltage at terminal 13 is greater than the voltage at terminal 9. A varying duty cycle is established in which the load is predominantly on with a cold sensor and predominantly off with a hot sensor. For precise temperature regulation, the time base of the ramp should be shorter than the thermal time constant of the system but longer than the period of the 60-Hz line. Fig. 10, which contains various waveforms for the system of Fig. 9, indicates that a typical variance of ±0.5°C might be expected at the sensor contact to the utensil. Overshoot of the set temperature is minimized with this approach, and scorching of any type is minimized.

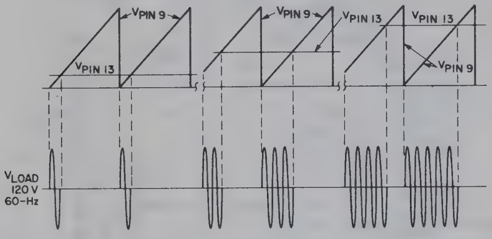


Fig. 10— Waveforms for the circuit of Fig. 9.

Now that the feasibility of a solid-state control for the range has been established, the various approaches can be joined and a system constructed. The phase-control circuit could be used for three top burners, the proportional control for the fourth burner, and the on-off oven/broiler control with the self-cleaning feature for the oven. Such a system would probably not challenge an electromechanical system on a cost basis, but performance would be improved in the oven control as cited above.

Central-Processor

Since the phase-control top-burner arrangement of Fig. 1 requires excessive handling in construction and does not lend itself to printed-circuit-board construction, it is recommended that a more compact, less expensive, total printed-circuit-board approach to the range control be investigated. Further, in order to cut system costs, it is recommended that similar circuit functions be multiplexed or shared as much as possible in one area in the circuit. A design that meets these requirements is shown in the block diagram of Fig. 11 and the schematic diagram of Fig. 12. The top burners L1, L2, L3, and L4

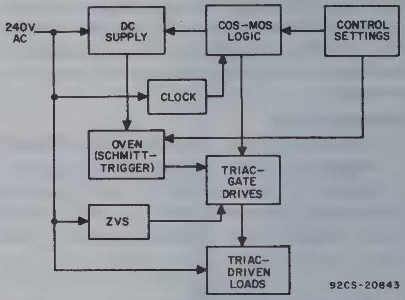

240V
AC
DC SUPPLY
COS-MOS LOGIC
CONTROL SETTINGS
CLOCK
OVEN (SCHMITT-TRIGGER)
TRIAC-GATE DRIVES
ZVS
TRIAC-DRIVEN LOADS
92CS-20843

Fig. 11— Block diagram of a central-processor control.

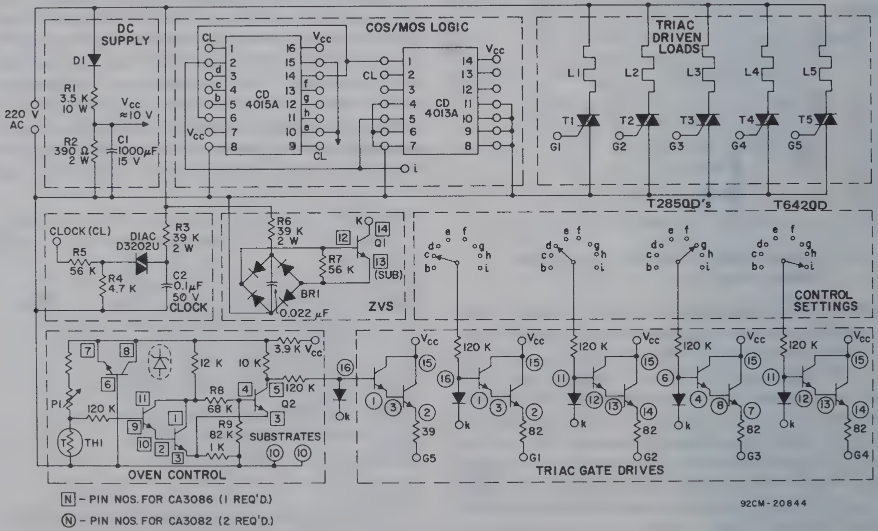

DC SUPPLY
D1
R1 3.5 K 10 W
Vcc ≈10 V
R2 390 Ω 2 W
C1 1000µF, 15 V
220 V AC
COS/MOS LOGIC
CD 4015A
CD 4013A
CL
Vcc
i
TRIAC DRIVEN LOADS
L1
L2
L3
L4
L5
T1
T2
T3
T4
T5
G1
G2
G3
G4
G5
T2850D's
T6420D
CLOCK (CL)
R5 56 K
DIAC D3202U
R3 39 K 2 W
R4 4.7 K
C2 0.1µF 50 V
CLOCK
R6 39 K 2 W
R7 56 K
Q1
(SUB)
BR1
0.022 µF
ZVS
CONTROL SETTINGS
OVEN CONTROL
P1
120 K
TH1
12 K
10 K
3.9 K
R8 68 K
R9 82 K
1 K
Q2
120 K
SUBSTRATES
TRIAC GATE DRIVES
Vcc
120 K
39
82
k
N - PIN NOS. FOR CA3086 (1 REQ'D.)
Ⓝ - PIN NOS. FOR CA3082 (2 REQ'D.)
92CM-20844

Fig. 12— Schematic diagram of the central-processor control of Fig. 11.

Fig. 12) are all controlled by the single logic bank of COS/MOS ircuitry composed of the RCA CD4013A and the RCA CD4015A; the logic diagrams of these devices are shown in Figs. 13 and 14.

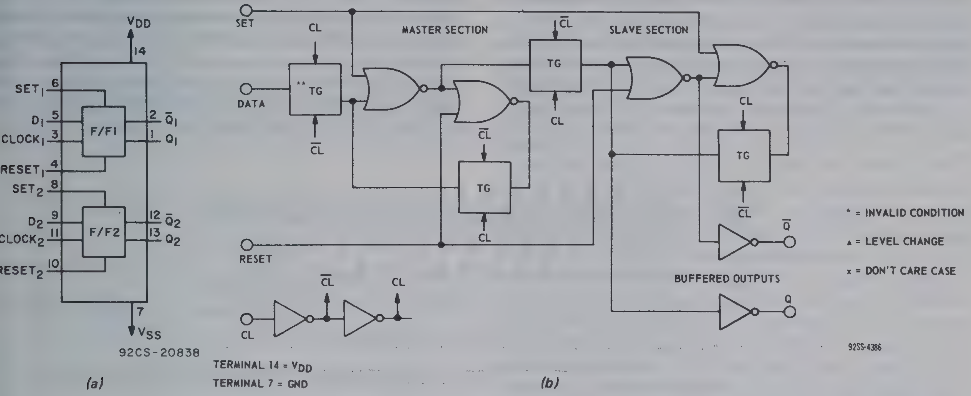

VDD
14
SET1 6
D1 5
CLOCK1 3
RESET1 4
F/F1
2 Q̄1
1 Q1
SET2 8
D2 9
CLOCK2 11
RESET2 10
F/F2
12 Q̄2
13 Q2
7
VSS
92CS-20838
(a)
SET
DATA
RESET
CL
CL̄
MASTER SECTION
SLAVE SECTION
** TG
TG
BUFFERED OUTPUTS
Q̄
Q
* = INVALID CONDITION
▲ = LEVEL CHANGE
x = DON'T CARE CASE
92SS-4386
TERMINAL 14 = VDD
TERMINAL 7 = GND
(b)

Fig. 13— Logic and block diagram of the CD4013A.

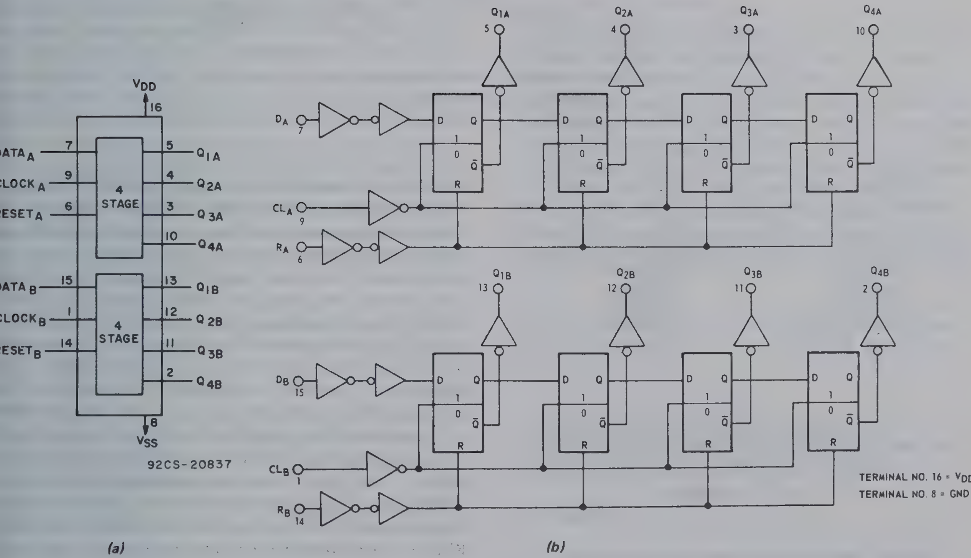

VDD
16
ATAA 7
LOCKA 9
ESETA 6
4 STAGE
5 Q1A
4 Q2A
3 Q3A
10 Q4A
ATAB 15
LOCKB 1
ESETB 14
4 STAGE
13 Q1B
12 Q2B
11 Q3B
2 Q4B
8
VSS
92CS-20837
(a)
DA 7
CLA 9
RA 6
DB 15
CLB 1
RB 14
D Q
1
0
Q̄
R
Q1A 5
Q2A 4
Q3A 3
Q4A 10
Q1B 13
Q2B 12
Q3B 11
Q4B 2
TERMINAL NO. 16 = VDD
TERMINAL NO. 8 = GND
(b)

Fig. 14— Logic and block diagram of the CD4015A.

The RCA CD4013A consists of two identical independent data-type flip-flops. Each flip-flop has independent data, set, reset, and clock inputs and Q and $\overline{Q}$ outputs. These devices can be used for shift-register applications and, by connecting the Q output to the data input, for counter and toggle applications. The logic level present at the D input is transferred to the Q output during the positive-going transition of the clock pulse. Setting or resetting is independent of the clock and is accomplished by a high level on the set or reset line, respectively.

The CD4015A consists of two identical independent four-stage serial-input/parallel-output registers. Each register has independent clock and reset inputs as well as a single serial data input. Q outputs are available from each of the four stages on both registers. All register stages are D-type master-slave flip-flops. The logic level present at the data input is transferred into the first register stage and shifted over one stage at each positive-going clock transition. Resetting of all stages is accomplished by a high level on the reset line. Register expansion to eight stages using one CD4015A package, or to more than eight stages using additional CD4015A's, is possible.

With the CD4015A connected as an eight-stage register and the CD4013A used as the reset, the waveforms of Fig. 15 result when clocking pulses are applied from the clock stage, a simple RC diac oscillator (60 Hz). The outputs of the COS/MOS register are fed to the eight-position rotary-selector switch for selection of the duty cycle to be applied to the load. The output of the rotary switch is connected to the drive triacs through the Darlington-connected triac gate drivers. These drivers are made up of pairs of transistors from the RCA CA3082, a seven-transistor, high-current (100 milliamperes), silicon, n-p-n array. The bases of the input transistors of the Darlington drivers are all connected to the collector of Q1, the zero-voltage sensing transistor, so that triac gate-drive pulses are applied only when the ac line voltage is approximately ±2.1-volts peak. That is, base drive shunted from the Darlington drivers by Q1 causes zero-voltage switching of the triacs and restricts the average power drain of the dc supply by pulsing the triac gates. This circuit arrangement results in minimized RFI. Fig. 16 demonstrates the power waveforms for the circuit

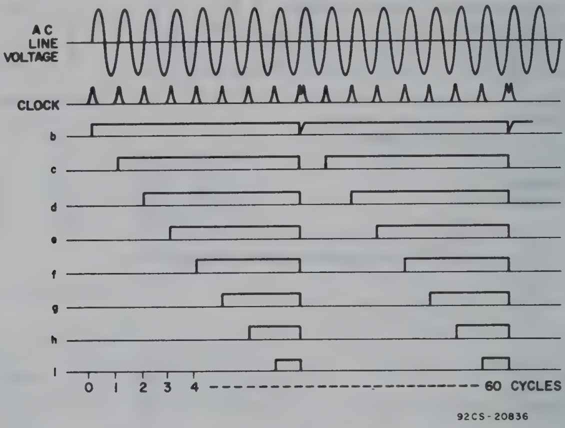


Fig. 15– Output waveforms from the clock stage of Fig. 12 when clocking pulses are applied to it.

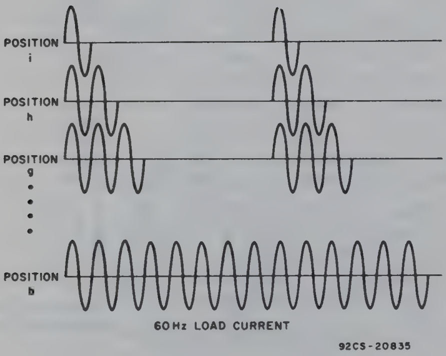


Fig. 16– Power-output waveforms for the circuit of Fig. 12.

of Fig. 12. Fig. 17 demonstrates the effect of the zero-voltage sensing transistor, Q1, and the relationship between the various COS/MOS outputs and the base drive and subsequent gate drive of the Darlington drivers. By using an additional selector switch, triac, and related gate circuitry (made up of spare transistors in the CA3082) a controllable convenience outlet can be provided. This outlet can be used for an electric fry-pan, coffee maker, waffle iron, toaster, etc., and can be controllable n the same manner as the top-burner elements.

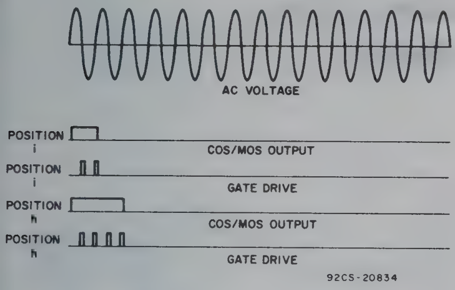


Fig. 17– Gating relationship waveforms for the circuit of Fig. 12.

An oven control is incorporated in the design by using an RCA CA3086, an array of five n-p-n transistors with one pair differentially-connected as a Schmitt trigger in closed-loop configuration. Again, the common dc supply of the system is used in addition to the zero-voltage sensing transistor, Q1. An dditional Darlington pair available in the CA3082 is used for riac gating. As shown in Fig. 12, an NTC sensor, TH1, forms a oltage divider with the potentiometer, P1, the temperature-elector switch. The input transistor of the Schmitt trigger is a Darlington pair to provide sensitivity. Resistor R8 is chosen to llow for the desired amount of circuit hysteresis. When the ensor is cold and has a large resistance, the Darlington input s turned on and causes output transistor Q1 to turn off. The V_{CC} fed to the zero-voltage sensing transistor and respective gate drive switches the oven on. As the desired oven tempera-ure is reached, the sensor resistance decreases and the voltage it controls drops below the switching threshold of the Schmitt trigger; this drop in voltage removes the gate drive to the oven. A PTC sensor could easily be used by inverting the sensor and potentiometer. Of course, with proper external switching of the oven elements and the incorporation of a fixed resistor to bias the Schmitt trigger to the high temperature of the self-cleaning mode, self-cleaning action can be accommodated by this system. Care must be taken, particularly with the location of the power triac for the oven, to afford the best possible ambient temperature conditions and heat sinking.

Conclusions

With the circuitry of Fig. 12, control of the temperature of the top burners is provided without the need for calibration of a sensor element, and the design is well suited for printed-circuit-board-module use. Extension of the circuit concept could lead to a future hybrid design incorporating custom chips. The nest of wiring which is now present in ranges is minimized by the use of the printed-circuit board. Zero-voltage switching of the power elements results in minimized RFI, while the single calibration between P1 and TH1 or an auxiliary calibration potentiometer is the only calibration necessary in the oven control. These concepts should lead to easier manufacture with limited in-line failures, because the printed-circuit-board modules could be tested before assembly into the range, and lower manufacturing costs because of the decreased amount of wiring. The history of solid-state dependability should also be reflected in the low amount of field failures.

References

1. "Application of RCA-CA3058 and RCA-CA3059 Zero-Voltage Switches in Thyristor Circuits", by George J. Granieri, RCA Application Note ICAN-6158.
2. "Applications and Extended Operating Characteristics for the RCA-CA3059 IC Zero-Voltage Switch", by H. M. Kleinman and A. Sheng, RCA Application Note ICAN-6268.
3. "Applications of the CA3080 and CA3080A High-Performance Operational Transconductance Amplifiers", by H. A. Wittlinger, RCA Application Note ICAN-6668.
4. "Linear Integrated Circuits–Building Blocks for Control Applications", by George J. Granieri, RCA Reprint ST-6053.

RCA
Solid State
Division

Thyristors / Rectifiers
Application Note
AN-6141

Power Switching Using Solid-State Relay

by T. C. McNulty

Solid-state relays make use of a semiconductor device for control of ac or dc power. Since, in most ac applications, the semiconductor element chosen for power control is the triac, this Note describes the triac as a power-switching element. Advantages and disadvantages of the active element over the electro-mechanical relay are discussed in general terms. Basic parameters, such as surge in-rush capability, transient-voltage ratings, suppression network, turn-off consideration and the different modes of triac gating are also discussed. AC power control is covered by various circuit designs for ON/OFF control, zero-voltage switching, and line-voltage isolation.

Power switching using electromechanical relays (EMR) is probably as old as the electrical industry is. The EMR is a controlled device having either an ON state or an OFF state capable of handling large amounts of power for a relatively low input power; it has widespread use in power and logic circuits. The relay comes in many forms (general purpose, telephone type, TO-5, reed, mercury wetted, etc.) and has various contact configurations. During the past few years, the EMR has been challenged by a new breed of relay which has no moving parts, is capable of handling large amounts of power for relatively low input power, and that comes in many package and circuit configurations. This new breed has been dubbed the "Solid-State Relay" or SSR, and uses transistors for dc power-control or triacs for ac power control. The SSR is particularly useful in areas in which increased reliability is required, and in which shock or mechanical fatigue impose severe limitations on the electromechanical relay. The major limitations to SSR use are economic factors, line isolation, immunity from line transients, and the need for multiple-pole arrangements.

TRIAC CONSTRUCTION

Thyristors (silicon controlled rectifiers and triacs) are semiconductor switches whose bistable state depends upon the regenerative feedback associated with a p-n-p-n structure. The SCR is a unidirectional device used primarily for dc and ac functions, whereas the triac is a bidirectional device used primarily for control of ac power.

The fabrication of a standard, glass-passivated triac requires the seven basic steps illustrated in Fig. 1 and delineated below.

1. The process begins with an n-type, high-resistivity, silicon wafer;
2. p layers are diffused deeply into both sides;
3. Silicon-dioxide diffusion masks are grown, and p+ regions are defined and diffused into the wafer;
4. A second oxide diffusion mask is grown, and n+ regions are defined and diffused into the wafer;
5. A silicon-dioxide etch mask is grown and defined. Grids and gate moats are etched into the wafer;

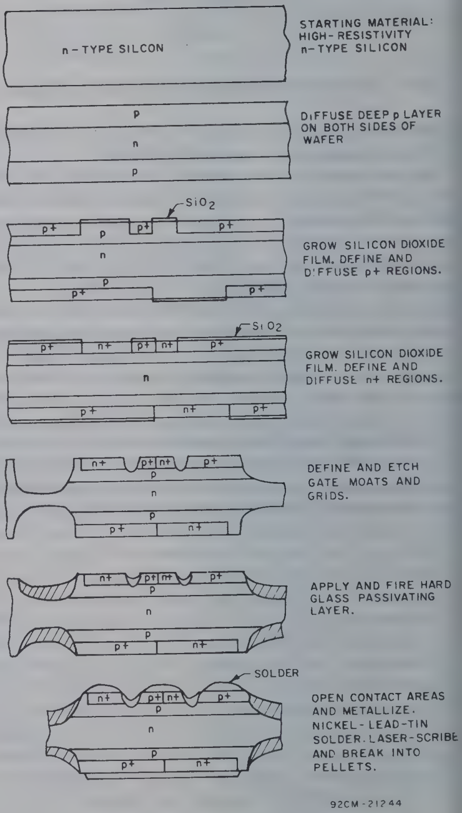

n-TYPE SILCON
STARTING MATERIAL: HIGH-RESISTIVITY n-TYPE SILICON
p
n
p
DIFFUSE DEEP p LAYER ON BOTH SIDES OF WAFER
SiO2
p+
p
p+
p+
n
p
p+
p+
GROW SILICON DIOXIDE FILM. DEFINE AND DIFFUSE p+ REGIONS.
SiO2
p+
n+
p+
n+
p+
n
p+
n+
p+
GROW SILICON DIOXIDE FILM. DEFINE AND DIFFUSE n+ REGIONS.
n+
p+
n+
p+
p
n
p
p+
n+
DEFINE AND ETCH GATE MOATS AND GRIDS.
n+
p+
n+
p+
p
n
p
p+
n+
APPLY AND FIRE HARD GLASS PASSIVATING LAYER.
SOLDER
n+
p+
n+
p+
p
n
p
p+
n+
OPEN CONTACT AREAS AND METALLIZE. NICKEL-LEAD-TIN SOLDER. LASER-SCRIBE AND BREAK INTO PELLETS.
92CM-21244

Fig.1 — The seven basic steps required in the fabrication of a standard, glass-passivated triac.

6. A hard glass-passivated layer is applied in the grids and gate moat;

7. Contact areas are opened on the wafer and nickel-lead-tin solder metallization is applied. The wafer is then laser-scribed and separated into pellets. Fig. 2 contains an isometric view of a completed triac and dimensions of three devices now available or in the design stage.

VOLTAGE AND TEMPERATURE RATINGS

The effects of voltage and temperature are important in thyristors because of the regenerative action of these devices, and because they are often required to support high voltages under high temperature conditions. The imposed voltages create a field at the junction interface, and the increased temperature releases additional surface ions. Should the field concentrate the additional surface charge and allow it to migrate into the gate region, non-gated turn-on may occur. Most manufacturers realize that the gate region must be terminated for high voltage/temperature operation, and a shunt resistance is built into the triac pellet during fabrication. This shunt reduces the immunity of the triac to non-gated turn-on. Additional reliability can be gained by operating the triac under less severe voltage/temperature conditions.

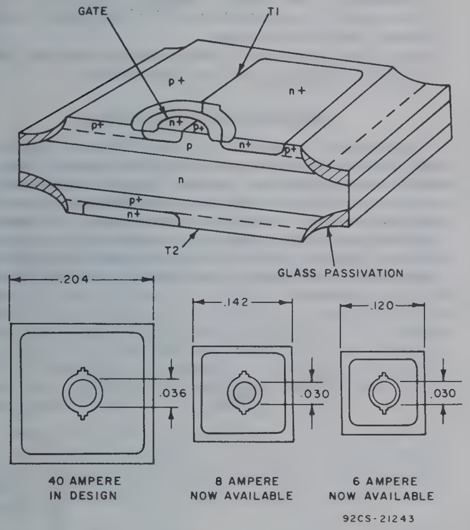


Fig.2 – An isometric view of a completed triac and dimensions of three devices now available or in the design stage.

IN-RUSH CURRENTS

One of the features that has made thyristors the work-horses of the power semiconductor industry is their ability to absorb in-rush currents many times in excess of their steady-state ratings. This unique feature results from the regenerative action of the thyristor, an action which maintains the internal beta at a level such that, under in-rush conditions, the charge density is equally distributed over the entire triac pellet. The equal charge distribution assures the presentation of a low impedance to the in-rush current. Each manufacturer clearly rates device surge capability from single cycle to multiple cycles. Since this rating cannot be exceeded repeatedly, care should be exercised in the actual application to provide a sufficient safety margin between the published ratings and the actual circuit in-rush currents.

Another important parameter associated with a triac is its di/dt rating, a parameter most significant during turn-on. With the initiation of a gate signal, the active area closest to the gate region is, essentially, turned on, and, for a few microseconds, the instantaneous power dissipation is a function of the rate of rise of the on-state current. This power dissipation may cause localized heating and result in silicon-lattice destruction and triac degradation. The di/dt ratings are a function of triac geometry and pellet size, and ratings of 100 A/μs are easily achieved. In most circuit applications, stray or actual-load inductance is present, and for the condition of di/dt = E_{pk}/L, it is easily seen that a few microhenries of inductance are all that are required to limit circuit di/dt to within the maximum rating. When di/dt ratings are exceeded, it is usually because of the RC snubber network in parallel with the triac. In such networks, stray inductance is essentially zero, and the magnitude of discharge current is limited by the snubber resistance. The di/dt in the snubber is not affected by the inductance added to quell the di/dt caused by the stray or actual-load inductance; only careful selection of RC-snubber-network components will eliminate this second source of di/dt and minimize triac failures.

TRANSIENT VOLTAGES

It is well known that triacs are susceptible to non-gated turn-on and possible damage as a result of transient voltages. Transients are generally caused in a triac by the switching of inductive loads on adjacent lines or in proximity to the device. If the transient voltage generated exceeds the critical rate-of-rise of the off-state voltage (dv/dt) then a displacement current (i = C·dv/dt) is generated which causes non-gated turn-on. Non-gated turn-on is not destructive if the energy transfer is within the maximum rating of the device; however, if the transient voltage does not exceed the off-state dv/dt rating, but does exceed the maximum voltage rating, then triac breakover occurs. Whether triac degradation occurs is dependent on whether the energy transfer is within the bulk silicon or the edge avalance.

Although the transient-voltage problem may seem critical, there are precautions that can be taken to minimize it. The use of RC snubbers in parallel with the triac can reduce the rate of imposed transients. This arrangement is most effective for fast rising, short-duration line disturbances. For critical applications, the use of a voltage-clipping device in addition to an RC snubber effectively suppresses both the rate of rise and magnitude of line-generated transients.

Another type of transient particularly prevalent in the area of inductive loads, and often overlooked, is the circuit-induced transient. Consider an inductive load in series with a triac and RC snubber network which also includes a switch for line-voltage interruption. With the triac in the off state, a leakage current flows which is a function of the characteristics of the load, the RC snubber network, and triac leakage. If the switch is momentarily opened when the triac is off, then a voltage transient (E = L·di/dt) is generated which can exceed the voltage rating of the triac, cause non-gated turn-on and abrupt energy transfer; and may result in damage to the triac. Again, the proper selection of RC-network components and voltage-clipping device will suppress the circuit-induced transient to a level compatible with the voltage rating of the triac.

COMMUTATING dv/dt

The term "turn-off time" is not associated with triacs since triacs are bidirectional, and reverse voltage is nothing more than a forward voltage to one-half of the triac chip. A new term, "critical-rate-of-rise-of-commutation-voltage", is used with triacs. The term describes the ability of the triac to turn off as the current passes through zero, or commutates. One must remember that the triac is a current-dependent device: current is injected into the gate to turn the device on, and current must be removed or allowed to pass through zero for turn-off regardless of what the source-voltage polarity is. Commutating dv/dt is less critical with resistive loads and most important with inductive loads. Consider an inductive load in which the load current lags the source voltage by a phase angle θ. As pointed out, triac commutation occurs at zero current, whereas the source voltage has some magnitude E. As the load current crosses the zero point, a small reverse current is established as a result of the charge in the n-type region. This charge, plus a displacement current ($i = C \cdot dv/dt$) resulting from the reapplied source voltage, can cause the triac to turn on in the absence of a proper gate signal. A minimum commutating dv/dt at rated current and at a specific operating case temperature should be defined in all triac applications; the circuit designer can use these specifications to choose an RC snubber network that will limit the reapplied dv/dt to within ratings. Loss of triac control as a result of commutating dv/dt does not degrade the characteristics of the triac. Proper RC snubber network selections for worst-case conditions of load power factor, current, and voltage are easily made by use of the charts shown in Fig.3.

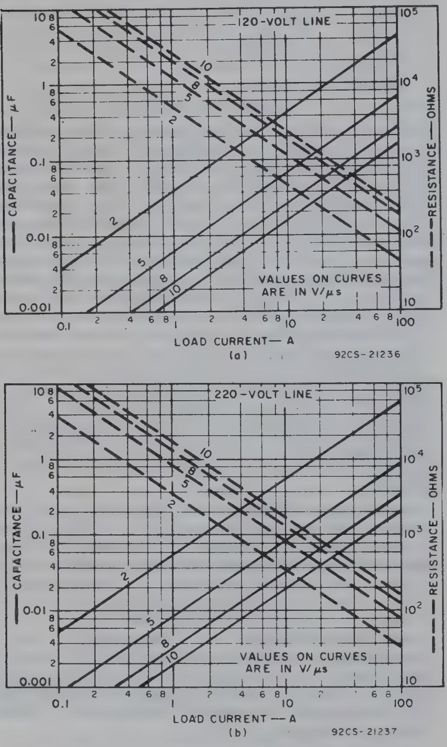


Fig.3 – (a) Snubber components for 200-volt peak on 120-volt line; (b) Snubber components for 400-volt peak on 220-volt line.

ADVANTAGES OF SSR's

Before the advantages of SSR's are discussed, the types available should be reviewed.

Two types of SSR are available: all solid-state and hybrids. The solid-state class employs solid-state devices for both logic and triac gating. Hybrids generally use a reed relay for triac gating for ac power control and so combine the electromechanical with solid state. In either class, the triac is used as the solid-state element for ac power control. A comparison of SSR's with electromechanical relays is given below.

Life: An EMR physically makes and breaks load current, and the relay contacts deteriorate with life.

SSR's: They have no moving parts, and may be designed to make and break at zero current. Regardless of the design, the triac always breaks at zero current.

Contact Bounce: Inherent with an EMR – zero for SSR's.

RFI: Inherent with EMR's – dependent on SSR design.

AFI: ("audio-frequency" interference). Terrible with EMR's, particularly when many relays are clacking about. Not noticeable with SSR's.

Environment: High humidity, corrosion, and explosive atmospheres usually dictates a sealed relay. SSR's may easily be potted.

Shock: The SSR is far superior.

Input Logic: EMR's can be operated from low-level logic. SSR's are design dependent, but offer complete versatility.

GENERAL CONTROL CIRCUITS

A simple triac control circuit, an ON/OFF circuit, is shown in Fig.4. With switch S1 open, the triac is off and essentially zero current is applied to the load. Actually, there will be leakage-current flow to the load; the amount of current is dependent on the applied voltage and triac case temperature. However, because the current is very small (less than one milliampere) compared to the load current, it can be neglected in this and the following circuits. (In specific applications in which leakage current may affect control it would have to be considered.)

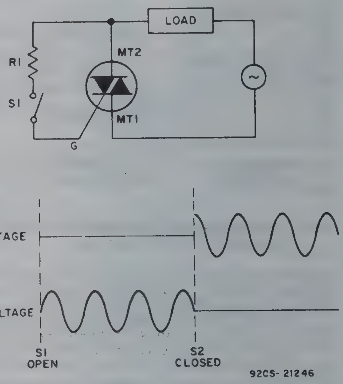


Fig.4 – ON/OFF control, non-synchronized.

To apply power to the load in Fig.4, switch S1 is closed to provide gate drive to the triac. Bias-resistor R1 is of the order of 68 to 100 ohms and provides the initial gate drive during every half cycle o applied voltage. The power consumption of R1 is very low (1/4 to 1/2 watt), because, when the triac is in the ON state, R1 is in paralle with the ON-state voltage of approximately 1.5 volts. This method of triac triggering, called anode firing, is an effective way of triggering because it uses the source voltage as a source of gate-current drive Maximum gate current is available for triac turn-on at peak line volt age until the device goes to the low-impedance state. In this state the current in R1 is reduced by the forward voltage drop. In effect bias resistor R1 is utilized only during the initial turn-on of the triac or for approximately two microseconds. In a typical application switch S1 would be replaced by a relay, and power control would be transferred by means of low-level-current relay contacts.

For control applications which require that variable power be delivered to a load, an inexpensive RC phase-control circuit is best. Fig.5 shows the basic triac-diac control circuit with the triac connected in series with the load. During the beginning of each half cycle the triac is in the OFF state; as a result, the entire line voltage is impressed across it. Because the triac is in parallel with the potentiometer and capacitor, the voltage across the triac drives the current through the potentiometer and charges the capacitor. When the capacitor voltage reaches the breakover voltage of the diac, V_{BO}, the capacitor discharges through the triac gate and turns it on. The line voltage is then transferred from the triac to the load for the remainder of that half cycle. This sequence is repeated for every half cycle of either polarity. If the potentiometer resistance is reduced, the capacitor charges more rapidly, the V_{BO} of the diac is reached earlier in the cycle, and the power applied to the load is increased. If the potentiometer resistance is increased, triggering occurs later and load power is reduced. The main disadvantage of this circuit is that it produces RFI.

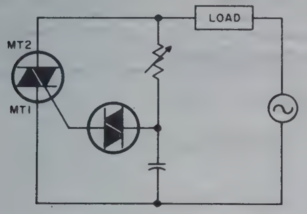


Fig.5 – RC phase control, variable power.

Although the basic light-control circuit operates with the component arrangement shown in Fig.5, additional components and sections are usually added to reduce hysteresis effects, extend the effective range of power control, and suppress radio-frequency interference.

TEMPERATURE-CONTROL CIRCUITS

A zero-voltage-switch, Fig.6, synchronized for line-pulse generation, in combination with a triac, is particularly well suited for temperature-control applications. The zero-voltage-switch/triac circuit may be used with an ON/OFF-type control or as a proportional control depending on the degree of regulation required. A simple, inexpensive, ON/OFF temperature controller is shown in Fig.7; a review of the functional block diagram of the zero-voltage-switch, Fig.6, will help in understanding the circuit. For every zero-voltage crossing, a zero crossing pulse is generated and directed to the triac gating circuit. If there is a demand for heat, the differential amplifier is in the open state, the triac gating circuit is open, and the triac is turned on at every zero-voltage crossing. When the demand for heat is satisfied, the differential amplifier is in the closed state; this inhibits the triac gating circuit and removes any further gate drive to the triac. Therefore, the key to the operation of this circuit is in the state of the differential amplifier. One side of the differential amplifier is biased to a reference voltage V_R, and the other side is biased to a voltage V_S which is dependent on a variable potentiometer setting and sensing resistor. As a result, whenever the bias voltage V_S exceeds the reference voltage V_R, the gating circuit is open and the triac is turned on for each zero-voltage crossing. The characteristics of an ON/OFF controller are well known; i.e., there are significant thermal overshoots and undershoots which result in a differential temperature above and below the reference temperature. The magnitude of the differential temperature is dependent on the mass of the heater and the time constant of the sensing element.

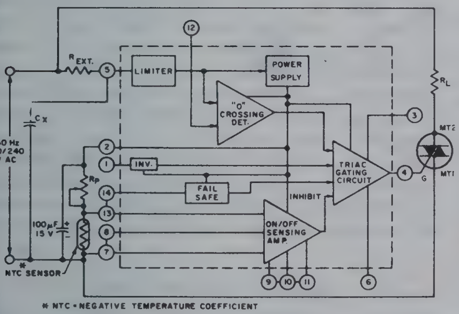


Fig.6 – Functional block diagram of the integrated-circuit zero-voltage-switch, CA3059.

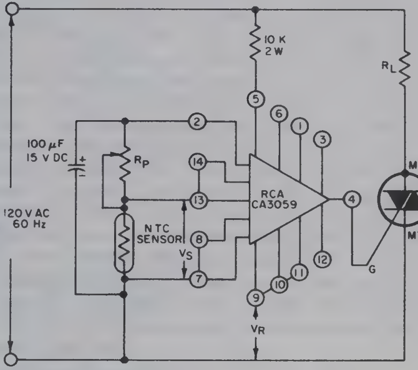


Fig.7 – CA3059 ON/OFF temperature controller.

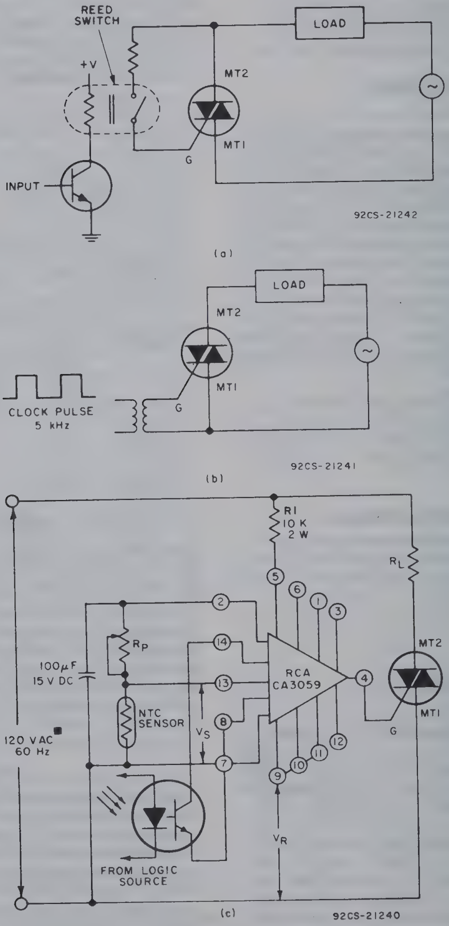
For precise temperature control, the technique of proportional control with synchronous switching is introduced. The proportional control differs from the ON/OFF control in that it allows a specified percentage of power (duty cycle) to be supplied to the load with a finite off time that, in turn, allows the heating element to "catch up" as a result of thermal lag. In effect, this scheme provides "anticipator control." Again, the key to circuit operation is in the state of the differential amplifier.

AC LINE ISOLATION

The design engineer often must provide dc-to-ac isolation. Complete isolation can be achieved by reed relays, pulse transformers, and light-activated devices. Selection of any one of these three approaches depends on the dc logic design and component economics. Fig.8 (a) shows a reed relay and transistor drive circuit which is effective in triac gating, although it does have moving parts. Fig.8 (b) uses a pulse transformer for isolation, and requires a form of clock pulse that can be transferred to the triac gate. In some applications, clock pulses may already be available; therefore the pulse-transformer approach is economical. This approach requires more components than that of Fig.8 (a), but it has no moving parts. The last approach, and, at present, probably the most expensive one, uses a light-activated device, such as the GaAs infrared (IR) emitter, to initiate triac gating. The light-activated device is coupled to a photosensitive transistor which, when turned on, provides inhibit logic for additional integrated circuits or, as in Fig. 8 (c), for a zero-voltage-switch application.

CONCLUSION

This paper has illuminated some of those areas most misunderstood or considered as problem areas in the application of triacs. The designer who thoroughly understands the characteristics and limitations, but most of all the advantages, of triacs, will have at his disposal a device that he can use to design power controllers that operate satisfactorily not only in normal applications, but also in severe physical and electrical environments. The triac has already proven to be a true power-semiconductor device, and is widely used in both commercial and industrial applications; restrictions on triac use in military applications, particularly in 400-Hz power systems, are gradually being lifted. It is inevitable, then, that the triac will evolve as the basic building block for ac power control in power-controller systems.


REED SWITCH
+V
LOAD
MT2
MT1
G
INPUT
92CS-21242
(a)
LOAD
MT2
MT1
G
CLOCK PULSE 5 kHz
92CS-21241
(b)
R1 10 K 2 W
RL
100µF 15 V DC
Rp
NTC SENSOR
VS
RCA CA3059
MT2
MT1
G
120 VAC 60 Hz
VR
FROM LOGIC SOURCE
(c)
92CS-21240

■For 220-V, 50/60-Hz Operation:
R1=22 K, 4 W

Fig.8 – (a) Isolation with reed relay; (b) isolation with pulse transformer; (c) isolation with light-activated devices.

RCA
Solid State
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Linear Integrated Circuits

Monolithic Silicon

ICAN-6182

Features and Applications of RCA Integrated-Circuit Zero-Voltage Switches (CA3058, CA3059, and CA3079)

by A. C. N. Sheng, G. J. Granieri, and J. Yellin

RCA-CA3058, CA3059 and CA3079 zero-voltage switches are monolithic integrated circuits designed primarily for use as trigger circuits for thyristors in many highly diverse ac power-control and power-switching applications. These integrated-circuit switches operate from an ac input voltage of 24, 120, 208 to 230, or 277 volts at 50, 60, or 400 Hz.

The CA3059 and CA3079 are supplied in a 14-terminal dual-in-line plastic package. The CA3058 is supplied in a 14-terminal dual-in-line ceramic package. The electrical and physical characteristics of each type are detailed in RCA Data Bulletin File No. 490.

RCA zero-voltage switches (ZVS) are particularly well suited for use as thyristor trigger circuits. These switches trigger the thyristors at zero-voltage points in the supply-voltage cycle. Consequently, transient load-current surges and radio-frequency interference (RFI) are substantially reduced. In addition, use of the zero-voltage switches also reduces the rate of change of on-state current (di/dt) in the thyristor being triggered, an important consideration in the operation of thyristors. These switches can be adapted for use in a variety of control functions by use of an internal differential comparator to detect the difference between two externally developed voltages. In addition, the availability of numerous terminal connections to internal circuit points greatly increases circuit flexibility and further expands the types of ac power-control applications to which these integrated circuits may be adapted. The excellent versatility of the zero-voltage switches is demonstrated by the fact that these circuits have been used to provide transient-free temperature control in self-cleaning ovens, to control gun-muzzle temperature in low-temperature environments, to provide sequential switching of heating elements in warm-air furnaces, to switch traffic signal lights at street intersections, and to effect other widely different ac power-control functions.

FUNCTIONAL DESCRIPTION

RCA zero-voltage switches are multistage circuits that employ a diode limiter, a zero-crossing (threshold) detector, an on-off sensing amplifier (differential comparator), and a Darlington output driver (thyristor gating circuit) to provide the basic switching action. The dc operating voltages for these stages is provided by an internal power supply that has sufficient current capability to drive external circuit elements, such as transistors and other integrated circuits. An important feature of the zero-voltage switches is that the output trigger pulses can be applied directly to the gate of a triac or a silicon controlled rectifier (SCR). The CA3058 and CA3059 also feature an interlock (protection) circuit that inhibits the application of these pulses to the thyristor in the event that the external sensor should be inadvertently opened or shorted. An external inhibit connection (terminal No. 1) is also available so that an external signal can be used to inhibit the output drive. This feature is not included in the CA3079; otherwise, the three integrated-circuit zero-voltage switches are electrically identical.

Over-all Circuit Operation

Fig. 1 shows the functional interrelation of the zero-voltage switch, the external sensor, the thyristor being triggered, and the load elements in an on-off type of ac power-control system. As shown, each of the zero-voltage switches incorporates four functional blocks as follows:

(1) Limiter-Power Supply – Permits operation directly from an ac line.

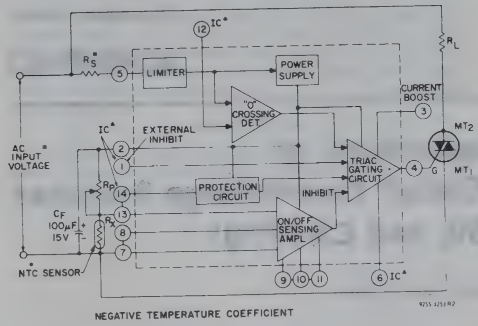
(2) Differential On/Off Sensing Amplifier – Tests the condition of external sensors or command signals. Hysteresis or proportional-control capability may easily be implemented in this section.

(3) Zero-Crossing Detector – Synchronizes the output pulses of the circuit at the time when the ac cycle is at a zero-voltage point and thereby eliminates radio-frequency inteference (RFI) when used with resistive loads.

(4) Triac Gating Circuit – Provides high-current pulses to the gate of the power-controlling thyristor.

In addition, the CA3058 and CA3059 provide the following important auxiliary functions (shown in Fig. 1):

(1) A built-in protection circuit that may be actuated to remove drive from the triac if the sensor opens or shorts.


IC▲
12
RS▲
5
LIMITER
POWER SUPPLY
"0" CROSSING DET.
CURRENT BOOST
3
RL
MT2
IC▲
EXTERNAL INHIBIT
AC INPUT VOLTAGE
2
1
TRIAC GATING CIRCUIT
4
G
MT1
RP
14
PROTECTION CIRCUIT
INHIBIT
CF 100µF 15V
13
RX
8
ON/OFF SENSING AMPL
7
NTC SENSOR
9
10
11
6
IC▲
92SS-4253R2
NEGATIVE TEMPERATURE COEFFICIENT

AC Input Voltage (50/60 or 400 Hz) V AC	Input Series Resistor (RS) kΩ	Dissipation Rating for RS W
24	2	0.5
120	10	2
208/230	20	4
277	25	5

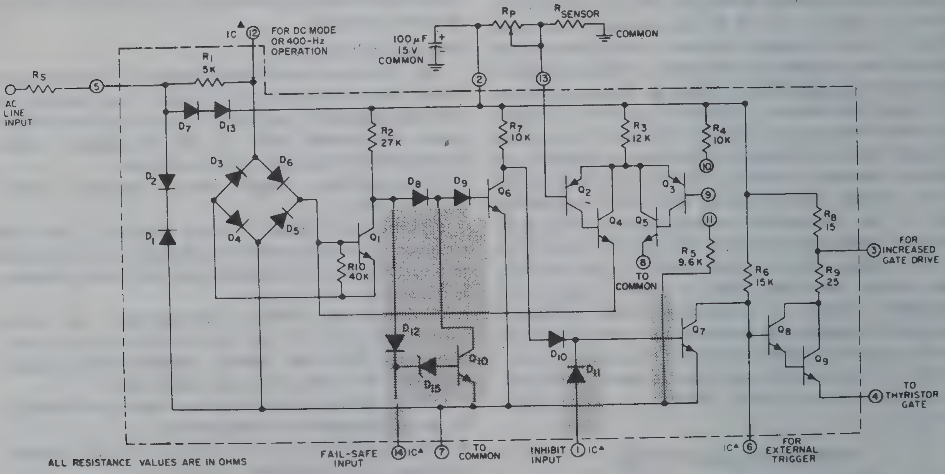
Fig. 1 – Functional block diagrams of the zero-voltage switches CA3058, CA3059, and CA3079.

(2) Thyristor firing may be inhibited through the action of an internal diode gate connected to terminal 1.

(3) High-power dc-comparator operation is provided by overriding the action of the zero-crossing detector. This override is accomplished by connecting terminal 12 to terminal 7. Gate current to the thyristor is continuous when terminal 13 is positive with respect to terminal 9.

Fig. 2 shows the detailed circuit diagram for the integrated-circuit zero-voltage switches. (The diagrams shown in Figs. 1 and 2 are representative of all three RCA zero-voltage switches, i.e., the CA3058, CA3059, and CA3079; the shaded areas indicate the circuitry that is not included in the CA3079.)

The limiter stage of the zero-voltage switch clips the incoming ac line voltage to approximately ±8 volts. This signal is then applied to the zero-voltage-crossing detector, which generates an output pulse each time the line voltage passes through zero. The limiter output is also applied to a rectifying diode and an external capacitor, C_F, that comprise the dc power supply. The power supply provides approximately 6 volts as the V_{CC} supply to the other stages of the zero-voltage switch. The on-off sensing amplifier is basically a differential comparator. The thyristor gating circuit contains a driver for direct triac triggering. The gating circuit is enabled when all the inputs are at a "high" voltage, i.e., the line voltage must be approximately zero volts, the sensing-amplifier output must be "high," the external voltage to terminal 1 must be a logical "0", and, for the CA3058 and CA3059, the output of the fail-safe circuit must be "high." Under these conditions, the thyristor (triac or SCR) is triggered when the line voltage is essentially zero volts.


RP
RSENSOR
COMMON
IC▲
12
FOR DC MODE OR 400-Hz OPERATION
100µF 15V COMMON
R1 5K
RS
5
AC LINE INPUT
2
13
D7
D13
R2 27K
R7 10K
R3 12K
R4 10K
10
D3
D6
D2
D8
D9
Q6
Q2
Q3
9
D1
D4
D5
Q1
Q4
Q5
11
R8 15
R10 40K
8
TO COMMON
R5 9.6K
R6 15K
3
FOR INCREASED GATE DRIVE
R9 25
D12
Q7
Q8
D10
Q10
D11
Q9
D15
TO THYRISTOR GATE
4
FAIL-SAFE INPUT
14
IC▲
7
TO COMMON
INHIBIT INPUT
1
IC▲
IC▲
6
FOR EXTERNAL TRIGGER
92CS-18076

ALL RESISTANCE VALUES ARE IN OHMS

NOTE: CIRCUITRY WITHIN SHADED AREAS, NOT INCLUDED IN CA3079

▲ IC = INTERNAL CONNECTION -- DO NOT USE (TERMINAL RESTRICTION APPLIES ONLY TO CA3079)

Fig. 2 – Schematic diagram of zero-voltage switches CA3058, CA3059, and CA3079.

hyristor Triggering Circuits

The diodes D_1 and D_2 in Fig. 2 form a symmetrical clamp hat limits the voltages on the chip to ±8 volts; the diodes D_7 nd D_{13} form a half-wave rectifier that develops a positive oltage on the external storage capacitor, C_F.

The output pulses used to trigger the power-switching yristor are actually developed by the zero-crossing detector nd the thyristor gating circuit. The zero-crossing detector onsists of diodes D_3 through D_6, transistor Q_1, and the ssociated resistors shown in Fig. 2. Transistors Q_1 and Q_6 rough Q_9 and the associated resistors comprise the thyristor ating circuit and output driver. These circuits generate the utput pulses when the ac input is at a zero-voltage point so at RFI is virtually eliminated when the zero-voltage switch nd thyristor are used with resistive loads.

The operation of the zero-crossing detector and thyristor ating circuit can be explained more easily if the on state (i.e., e operating state in which current is being delivered to the yristor gate through terminal 4) is considered as the perating condition of the gating circuit. Other circuit ements in the zero-voltage switch inhibit the gating circuit less certain conditions are met, as explained later.

In the on state of the thyristor gating circuit, transistors Q_8 nd Q_9 are conducting, transistor Q_7 is off, and transistor Q_6 on. Any action that turns on transistor Q_7 removes the drive om transistor Q_8 and thereby turns off the thyristor. ransistor Q_7 may be turned on directly by application of a inimum of +1.2 volts at 10 microamperes to the xternal-inhibit input, terminal 1. (If a voltage of more than 5 volts is available, an external resistance must be added in ries with terminal 1 to limit the current to 1 milliampere.) iode D_{10} isolates the base of transistor Q_7 from other signals hen an external-inhibit signal is applied so that this signal is e highest priority command for normal operation. (Although ounding of terminal 6 creates a higher-priority inhibit nction, this level is not compatible with normal DTL or TTL gic levels.) Transistor Q_7 may also be activated by turning f transistor Q_6 to allow current flow from the power supply rough resistor R_7 and diode D_{10} into the base of Q_7. ansistor Q_6 is normally maintained in conduction by current at flows into its base through resistor R_2 and diodes D_8 and 9 when transistor Q_1 is off.

Transistor Q_1 is a portion of the zero-crossing detector. hen the voltage at terminal 5 is greater than +3 volts, current n flow through resistor R_1, diode D_6, the base-to-emitter nction of transistor Q_1, and diode D_4 to terminal 7 to turn Q_1. This action inhibits the delivery of a gate-drive output gnal at terminal 4. For negative voltages at terminal 5 that ve magnitudes greater than 3 volts, the current flows rough diode D_5, the emitter-to-base junction of transistor $_1$, diode D_3, and resistor R_1, and again turns on transistor $_1$. Transistor Q_1 is off only when the voltage at terminal 5 is ss than the threshold voltage of approximately ±2 volts. hen the integrated-circuit zero-voltage switch is connected as shown in Fig. 1, therefore, the output is a narrow pulse which is approximately centered about the zero-voltage time in the cycle, as shown in Fig. 3. In some applications, however, particularly those that use either slightly inductive or low-power loads, the thyristor load current does not reach the latching-current value* by the end of this pulse. An external capacitor C_X connected between terminal 5 and 7, as shown in Fig. 4, can be used to delay the pulse to accommodate such loads. The amount of pulse stretching and delay is shown in Figs. 5(a) and 5(b).

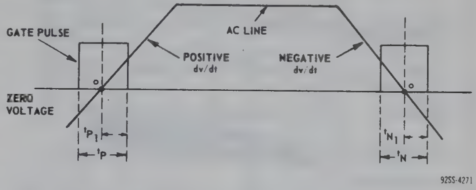


Fig. 3 – Waveform showing output-pulse duration of the zero-voltage switch.

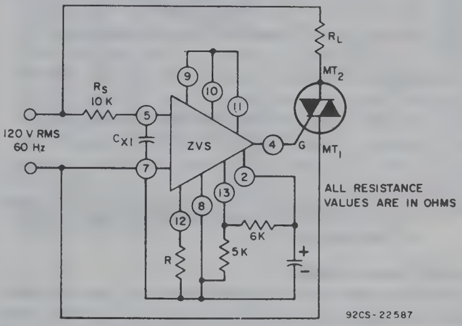


Fig. 4 – Use of a capacitor between terminals 5 and 7 to delay the output pulse of the zero-voltage switch.

Continuous gate current can be obtained if terminal 12 is connected to terminal 7 to disable the zero-crossing detector. In this mode, transistor Q_1 is always off. This mode of operation is useful when comparator operation is desired or when inductive loads must be switched. (If the capacitance in the load circuit is low, most RFI is eliminated.) Care must be taken to avoid overloading of the internal power supply in this mode. A sensitive-gate thyristor should be used, and a resistor should be placed between terminal 4 and the gate of the thyristor to limit the current, as pointed out later under **Special Application Considerations.**

Fig. 6 indicates the timing relationship between the line voltage and the zero-voltage- switch output pulses. At 60 Hz, the pulse is typically 100 microseconds wide; at 400 Hz, the pulse width is typically 12 microseconds. In the basic circuit shown, when the dc logic signal is "high", the output is disabled; when it is "low", the gate pulses are enabled.

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he latching current is the minimum current required to sustain onduction immediately after the thyristor is switched from the off o the on state and the gate signal is removed.

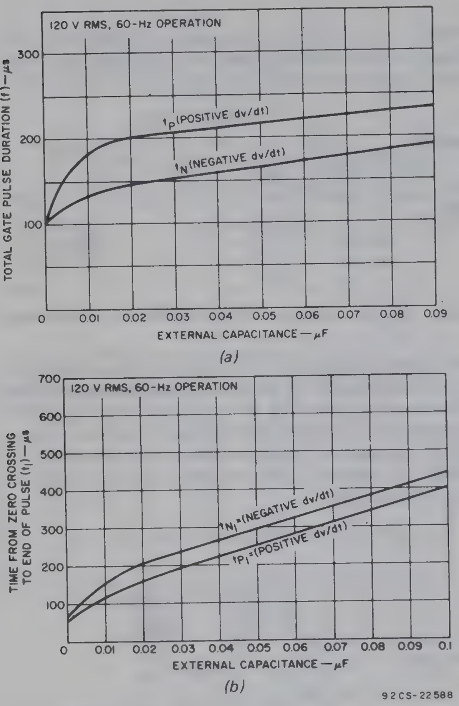
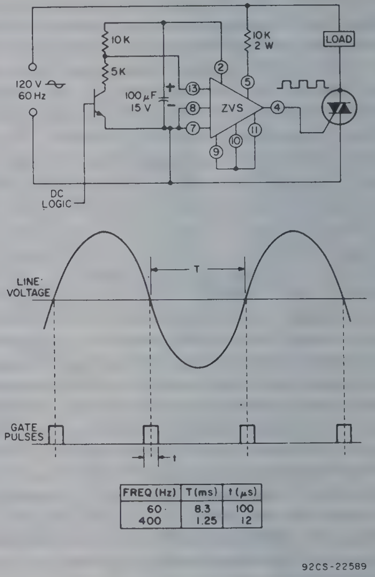


Fig. 5 – Curves showing effect of external capacitance on (a) the total output-pulse duration, and (b) the time from zero crossing to the end of the pulse.

On-Off Sensing Amplifier

The discussion thus far has considered only cases in which pulses are present all the time or not at all. The differential sense amplifier consisting of transistors Q_2, Q_3, Q_4, and Q_5 (shown in Fig. 2) makes the zero-voltage switch a flexible power-control circuit. The transistor pairs Q_2-Q_4 and Q_3-Q_5 form a high-beta composite p-n-p transistors in which the emitters of transistors Q_4 and Q_5 act as the collectors of the composite devices. These two composite transistors are connected as a differential amplifier with resistor R_3 acting as a constant-current source. The relative current flow in the two "collectors" is a function of the difference in voltage between the bases of transistors Q_2 and Q_3. Therefore, when terminal 13 is more positive than terminal 9, little or no current flows in the "collector" of the transistor pair Q_2-Q_4. When terminal 13 is negative with respect to terminal 9, most of the current flows through that path, and none in terminal 8. When current flows in the transistor pair Q_2-Q_4, the path is from the supply through R_3, through the transistor pair Q_2-Q_4, through the base-emitter junction of transistor Q_1, and finally through the diode D_4 to terminal 7. Therefore, when V_{13} is equal to or more negative than V_9, transistor Q_1 is on, and the output is inhibited.

In the circuit shown in Fig. 1, the voltage at terminal 9 is derived from the supply by connection of terminals 10 and 11 to form a precision voltage divider. This divider forms one side of a transducer bridge, and the potentiometer R_p and the negative-temperature-coefficient (NTC) sensor form the other side. At low temperatures, the high resistance of the sensor causes terminal 13 to be positive with respect to terminal 9 so that the thyristor fires on every half-cycle, and power is applied to the load. As the temperature increases, the sensor resistance decreases until a balance is reached, and V_{13} approaches V_9. At this point, the transistor pair Q_2-Q_4 turns on and inhibits any further pulses. The controlled temperature is adjusted by variation of the value of the potentiometer R_p. For cooling service, either the positions of R_p and the sensor may be reversed or terminals 9 and 13 may be interchanged.



FREQ (Hz)	T(ms)	t (μs)
60	8.3	100
400	1.25	12

Fig. 6 – Timing relationship between the output pulses of the RC zero-voltage switch and the ac line voltage.

The low bias current of the sensing amplifier permi operation with sensor impedances of up to 0.1 megohm balance without introduction of substantial error (i.e., great than 5 per cent). The error may be reduced if the intern bridge elements, resistors R_4 and R_5, are not used, but a replaced with resistances which equal the sensor impedanc The minimum value of sensor impedance is restricted by tl current drain on the internal power supply. Operation of tl zero-voltage switch with low-impedance sensors is discusse later under **Special Application Considerations**. The volta applied to terminal 13 must be greater than 1.8 volts at times to assure proper operation.

Protection Circuit

A special feature of the CA3058 and CA3059 zero-voltage switches is the inclusion of an interlock type of circuit. This circuit removes power from the load by interrupting the thyristor gate drive if the sensor either shorts or opens. However, use of this circuit places certain constraints upon the user. Specifically, effective protection-circuit operation is dependent upon the following conditions:

(1) The circuit configuration of Fig. 1 is used, with an internal supply, no external load on the supply, and terminal 14 connected to terminal 13.

(2) The value of potentiometer R_p and of the sensor resistance must be between 2000 ohms and 0.1 megohm.

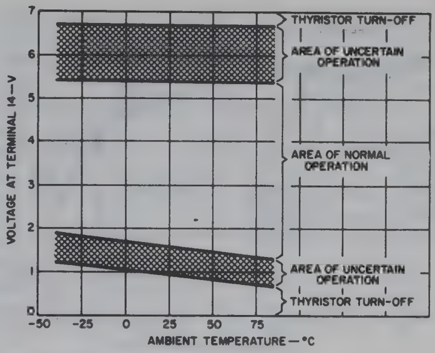
(3) The ratio of sensor resistance and R_p must be greater than 0.33 and less than 3.0 for all normal conditions. (If either of these ratios is not met with an unmodified sensor, a series resistor or a shunt resistor must be added to avoid undesired activation of the circuit.)

The protective feature may be applied to other systems when operation of the circuit is understood. The protection circuit consists of diodes D_{12} and D_{15} and transistor Q_{10}. Diode D_{12} activates the protection circuit if the sensor shown in Fig. 1 shorts or its resistance drops too low in value, as follows: Transistor Q_6 is on during an output pulse so that the junction of diodes D_8 and D_{12} is 3 diode drops (approximately 2 volts) above terminal 7. As long as V_{14} is more positive or only 0.15 volt negative with respect to that point, diode D_{12} does not conduct, and the circuit operates normally. If the voltage at terminal 14 drops to 1 volt, the anode of diode D_8 can have a potential of only 1.6 to 1.7 volts, and current does not flow through diodes D_8 and D_9 and transistor Q_6. The thyristor then turns off.

The actual threshold is approximately 1.2 volts at room temperature, but decreases 4 millivolts per degree C at higher temperatures. As the sensor resistance increases, the voltage at terminal 14 rises toward the supply voltage. At a voltage of approximately 6 volts, the zener diode D_{15} breaks down and turns on transistor Q_{10}, which then turns off transistor Q_6 and the thyristor. If the supply voltage is not at least 0.2 volt more positive than the breakdown voltage of diode D_{15}, activation of the protection circuit is not possible. For this reason, loading the internal supply may cause this circuit to malfunction, as may selection of the wrong external supply voltage. Fig. 7 shows a guide for the proper operation of the protection circuit when an external supply is used with a typical integrated-circuit zero-voltage switch.

SPECIAL APPLICATION CONSIDERATIONS

As pointed out previously, the RCA integrated-circuit zero-voltage switches (CA3058, CA3059, and CA3079) are exceptionally versatile units that can be adapted for use in a wide-variety of power-control applications. Full advantage of this versatility can be realized, however, only if the user has a basic understanding of several fundamental considerations that apply to certain types of applications of the zero-voltage switches.

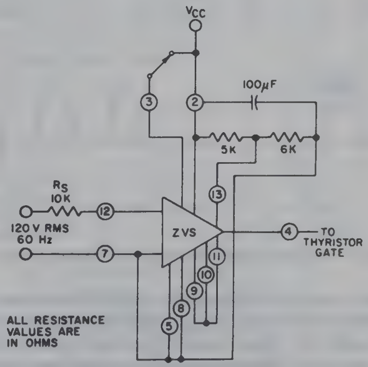


92CS-22590

Fig. 7 – Operating regions for built-in protection circuits of a typical zero-voltage switch.

Operating-Power Options

Power to the zero-voltage switch may be derived directly from the ac line, as shown in Fig. 1, or from an external dc power supply connected between terminals 2 and 7, as shown in Fig. 8. When the zero-voltage switch is operated directly from the ac line, a dropping resistor R_S of 5,000 to 10,000 ohms must be connected in series with terminal 5 to limit the current in the switch circuit. The optimum value for this resistor is a function of the average current drawn from the internal dc power supply, either by external circuit elements or by the thyristor trigger circuits, as shown in Fig. 9. The chart shown in Fig. 1 indicates the value and dissipation rating of the resistor R_S for ac line voltages of 24, 120, 208 to 230, and 277 volts.



92CS-22591

Fig. 8 – Operation of the zero-voltage switch from an external dc power supply connected between terminals 2 and 7.

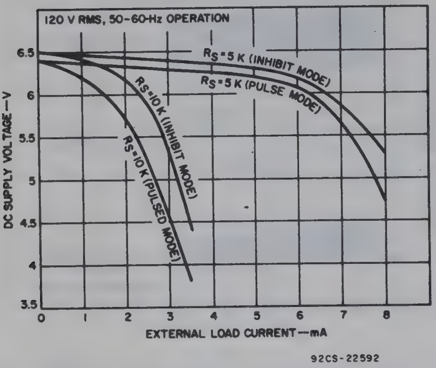


Fig. 9 – DC supply voltage as a function of external load current for several values of dropping resistance R_S.

Half-Cycling Effect

The method by which the zero-voltage switch senses the zero crossing of the ac power results in a half-cycling phenomenon at the control point. Fig. 10 illustrates this phenomenon. The zero-voltage switch senses the zero-voltage crossing every half-cycle, and an output, for example pulse No. 4, is produced to indicate the zero crossing. During the remaining 8.3 milliseconds, however, the differential amplifier in the zero-voltage switch may change state and inhibit any further output pulses. The uncertainity region of the differential amplifier, therefore, prevents pulse No. 5 from triggering the triac during the negative excursion of the ac line voltage.

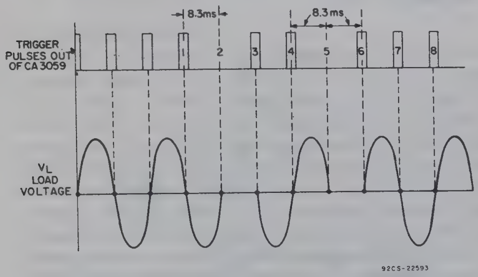
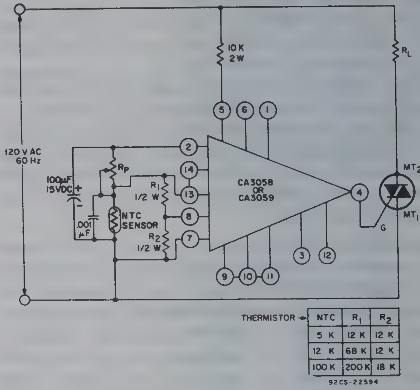

8.3ms
8.3ms
TRIGGER PULSES OUT OF CA3059
1
2
3
4
5
6
7
8
VL LOAD VOLTAGE
92CS-22593

Fig. 10 – Half-cycling phenomenon in the zero-voltage switch.

When a sensor with low sensitivity is used in the circuit, the zero-voltage switch is very likely to operate in the linear mode. In this mode, the output trigger current may be sufficient to trigger the triac on the positive-going cycle, but insufficient to trigger the device on the negative-going cycle of the triac supply voltage. This effect introduces a half-cycling phenomenon, i.e., the triac is turned on during the positive half-cycle and turned off during the negative half-cycle.

Several techniques may be used to cope with the half-cycling phenomenon. If the user can tolerate some hysteresis in the control, then positive feedback can be added around the differential amplifier. Fig. 11 illustrates this technique. The tabular data in the figure lists the recommended values of resistors R_1 and R_2 for different sensor impedances at the control point.


120 V AC 60 Hz
10 K 2W
RL
100µF 15VDC
.001 µF
RP
R1 1/2 W
NTC SENSOR
R2 1/2 W
CA3058 OR CA3059
MT2
MT1
G
THERMISTOR
92CS-22594

NTC	R1	R2
5 K	12 K	12 K
12 K	68 K	12 K
100 K	200 K	18 K

Fig. 11 – CA3058 or CA3059 on-off controller with hysteresis.

If a significant amount (greater than ±10%) of controlled hysteresis is required, then the circuit shown in Fig. 12 may be employed. In this configuration, external transistor Q_1 can be used to provide an auxiliary timed-delay function.

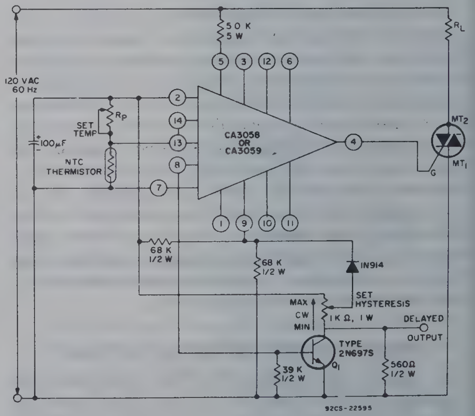

120 VAC 60 Hz
50 K 5 W
RL
SET TEMP
RP
100µF
NTC THERMISTOR
CA3058 OR CA3059
MT2
MT1
G
68 K 1/2 W
68 K 1/2 W
IN914
SET HYSTERESIS
MAX
CW
MIN
1 K Ω, 1 W
DELAYED OUTPUT
TYPE 2N697S
Q1
39 K 1/2 W
560Ω 1/2 W
92CS-22595

Fig. 12 – CA3058 or CA3059 on-off controller with controlled hysteresis.

For applications that require complete elimination of half-cycling without the addition of hysteresis, the circuit shown in Fig. 13 may be employed. This circuit uses a

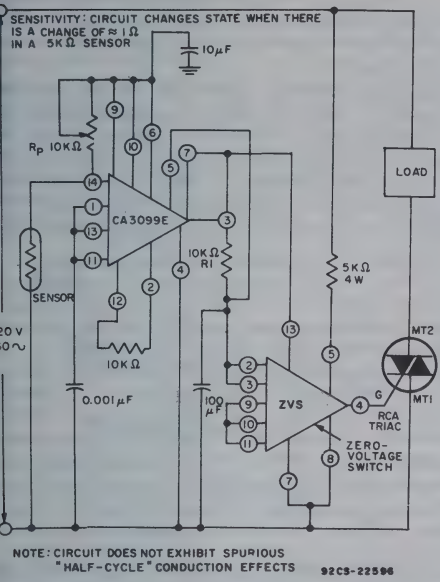

SENSITIVITY: CIRCUIT CHANGES STATE WHEN THERE IS A CHANGE OF ≈ 1 Ω IN A 5K Ω SENSOR
10μF
R_P 10KΩ
CA3099E
SENSOR
10KΩ
0.001μF
10KΩ R1
100 μF
ZVS
5KΩ 4W
LOAD
MT2
MT1
G
RCA TRIAC
ZERO-VOLTAGE SWITCH
20 V
0~
NOTE: CIRCUIT DOES NOT EXHIBIT SPURIOUS "HALF-CYCLE" CONDUCTION EFFECTS
92CS-22596

Fig. 13 – Sensitive temperature control.

CA3099E integrated-circuit programmable comparator with a zero-voltage switch. A block diagram of CA3099E is shown in Fig. 14. Because the CA3099E contains an integral flip-flop, its output will be in either a "0" or "1" state. Consequently the zero-voltage switch cannot operate in the linear mode, and spurious half-cycling operation is prevented. When the signal-input voltage at terminal 14 of the CA3099E is equal to or less than the "low" reference voltage (LR), current flows from the power supply through resistor R_1, and a logic "0" is applied to terminal 13 of the zero-voltage switch. This condition turns off the triac. The triac remains off until the signal-input voltage rises to or exceeds the "high" reference voltage (HR), thereby effecting a change in the state of the flip-flop so that a logic "1" is applied to terminal 13 of the zero-voltage switch, and triggers the triac on.

"Proportional Control" Systems

The on-off nature of the control shown in Fig. 1 causes some overshoot that leads to a definite steady-state error. The addition of hysteresis adds further to this error factor. However, the connections shown in Fig. 15(a) can be used to add proportional control to the system. In this circuit, the sense amplifier is connected as a free-running multivibrator. At balance, the voltage at terminal 13 is much less than the voltage at terminal 9. The output will be inhibited at all times until the voltage at terminal 13 rises to the design differential voltage between terminals 13 and 9; then proportional control resumes. The voltage at terminal 13 is as shown in Fig. 15(b). When this voltage is more positive than the threshold, power is

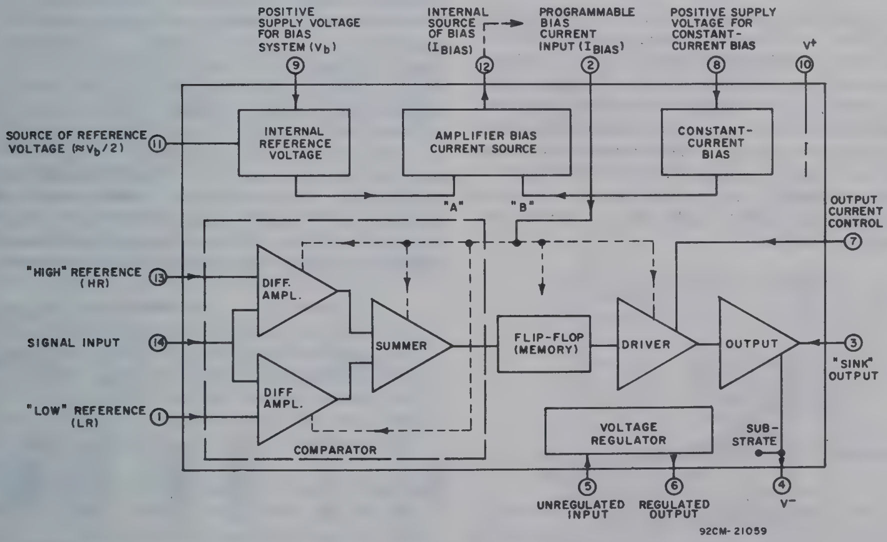

POSITIVE SUPPLY VOLTAGE FOR BIAS SYSTEM (V_b)
INTERNAL SOURCE OF BIAS (I_{BIAS})
PROGRAMMABLE BIAS CURRENT INPUT (I_{BIAS})
POSITIVE SUPPLY VOLTAGE FOR CONSTANT-CURRENT BIAS
V+
SOURCE OF REFERENCE VOLTAGE (≈V_b/2)
INTERNAL REFERENCE VOLTAGE
AMPLIFIER BIAS CURRENT SOURCE
CONSTANT-CURRENT BIAS
"A"
"B"
OUTPUT CURRENT CONTROL
"HIGH" REFERENCE (HR)
SIGNAL INPUT
"LOW" REFERENCE (LR)
DIFF. AMPL.
DIFF AMPL.
SUMMER
COMPARATOR
FLIP-FLOP (MEMORY)
DRIVER
OUTPUT
"SINK" OUTPUT
VOLTAGE REGULATOR
SUB-STRATE
UNREGULATED INPUT
REGULATED OUTPUT
V−
92CM-21059

Fig. 14 – Block diagram of CA3099E integrated-circuit programmable comparator.

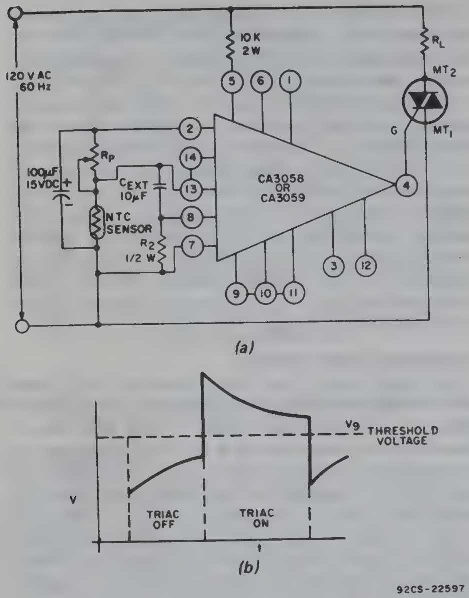


Fig. 15 – Use of the CA3058 or CA3059 in a typical heating control with proportional control: (a) schematic diagram, and (b) waveform of voltage at terminal 13.

applied to the load so that the duty cycle is approximately 50 per cent. With a 0.1 megohm sensor and values of R_p = 0.1 megohm, R_2 = 10,000 ohms, and C_{EXT} = 10 microfarads, a period greater than 3 seconds is achieved. This period should be much shorter than the thermal time constant of the system. A change in the value of any of these elements changes the period, as shown in Fig. 16. As the resistance of the sensor changes, the voltage on terminal 13 moves relative to V_9. A cooling sensor moves V_{13} in a positive direction. The triac is on for a larger portion of the pulse cycle and increases the average power to the load.

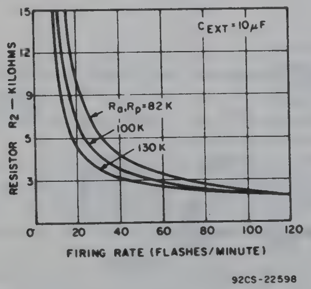


Fig. 16 – Effect of variations in time-constant elements on period.

As in the case of the hysteresis circuitry described earlier, some special applications may require more sophisticated systems to achieve either very precise regions of control or very long periods.

Zero-voltage switching control can be extended to applications in which it is desirable to have constant control of the temperature and a minimization of system hysteresis. A closed-loop top-burner control in which the temperature of the cooking utensil is sensed and maintained at a particular value is a good example of such an application; the circuit for this control is shown in Fig. 17. In this circuit, a unijunction oscillator is outboarded from the basic control by means of the internal power supply of the zero-voltage switch. The output of this ramp generator is applied to terminal 9 of the zero-voltage switch and establishes a varied reference to the differential amplifier. Therefore, gate pulses are applied to the triac whenever the voltage at terminal 13 is greater than the voltage at terminal 9. A varying duty cycle is established in which the load is predominantly on with a cold sensor and predominantly off with a hot sensor. For precise temperature regulation, the time base of the ramp should be shorter than the thermal time constant of the system but longer than the period of the 60-Hz line. Fig. 18, which contains various waveforms for the system of Fig. 17, indicates that a typical variance of ±0.5°C might be expected at the sensor contact to the utensil. Overshoot of the set temperature is minimized with this approach, and scorching of any type is minimized.

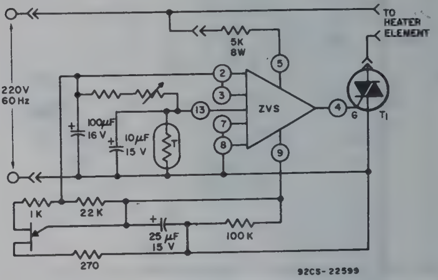


Fig. 17 – Schematic diagram of proportional zero-voltage-switching control.

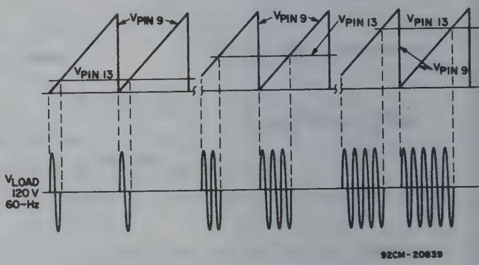


Fig. 18 – Waveforms for the circuit of Fig. 17.

ffect of Thyristor Load Characteristics

The zero-voltage switch is designed primarily to gate a yristor that switches a resistive load. Because the output ulse supplied by the switch is of short duration, the latching urrent of the triac becomes a significant factor in determining hether other types of loads can be switched. (The tching-current value determines whether the triac will remain conduction after the gate pulse is removed.) Provisions are cluded in the zero-voltage switch to accommodate inductive ads and low-power loads. For example, for loads that are less an approximately 4 amperes rms or that are slightly ductive, it is possible to retard the output pulse with respect the zero-voltage crossing by insertion of the capacitor C_X om terminal 5 to terminal 7. The insertion of capacitor C_X ermits switching of triac loads that have a slight inductive omponent and that are greater than approximately 200 watts or operation from an ac line voltage of 120 volts rms). owever, for loads less than 200 watts (for example, 0 watts), it is recommended that the user employ the 2300B* sensitive-gate triac with the zero-voltage switch ecause of the low latching-current requirement of this triac.

For loads that have a low power factor, such as a solenoid alve, the user may operate the zero-voltage switch in the dc ode. In this mode, terminal 12 is connected to terminal 7, nd the zero-crossing detector is inhibited. Whether a "high" r "low" voltage is produced at terminal 4 is then dependent nly upon the state of the differential comparator within the tegrated-circuit zero-voltage switch, and not upon the zero rossing of the incoming line voltage. Of course, in this mode f operation, the zero-voltage switch no longer operates as a ero-voltage switch. However, for many applications that volve the switching of low-current inductive loads, the mount of RFI generated can frequently be tolerated.

For switching of high-current inductive loads, which must e turned on at zero line current, the triggering technique mployed in the dual-output over-under temperature ontroller and the transient-free switch controller described ubsequently in this Note is recommended.

witching of Inductive Loads

For proper driving of a thyristor in full-cycle operation, ate drive must be applied soon after the voltage across the evice reverses. When resistive loads are used, this reversal ccurs as the line voltage reverses. With loads of other power actors, however, it occurs as the current through the load ecomes zero and reverses.

There are several methods for switching an inductive load at e proper time. If the power factor of the load is high (i.e., if e load is only slightly inductive), the pulse may be delayed y addition of a suitable capacitor between terminals 5 and 7, s described previously. For highly inductive loads, however, is method is not suitable, and different techniques must be sed.

If gate current is continuous, the triac automatically ommutates because drive is always present when the voltage everses. This mode is established by connection of terminals 7 nd 12. The zero-crossing detector is then disabled so that urrent is supplied to the triac gate whenever called for by the sensing amplifier. Although the RFI-eliminating function of the zero-voltage switch is inhibited when the zero-crossing detector is disabled, there is no problem if the load is highly inductive because the current in the load cannot change abruptly.

Circuits that use a sensitive-gate triac to shift the firing point of the power triac by approximately 90 degrees have been designed. If the primary load is inductive, this phase shift corresponds to firing at zero current in the load. However, changes in the power factor of the load or tolerances of components will cause errors in this firing time.

The circuit shown in Fig. 19 uses a CA3086 integrated-circuit transistor array to detect the absence of load current by sensing the voltage across the triac. The internal zero-crossing detector is disabled by connection of terminal 12 to terminal 7, and control of the output is made through the external inhibit input, terminal 1. The circuit permits an output only when the voltage at point A exceeds two V_{BE} drops, or 1.3 volts. When A is positive, transistors Q_3 and Q_4 conduct and reduce the voltage at terminal 1 below the inhibit state. When A is negative, transistors Q_1 and Q_2 conduct. When the voltage at point A is less than ±1.3 volts, neither of the transistor pairs conducts; terminal 1 is then pulled positive by the current in resistor R_3, and the output in inhibited.

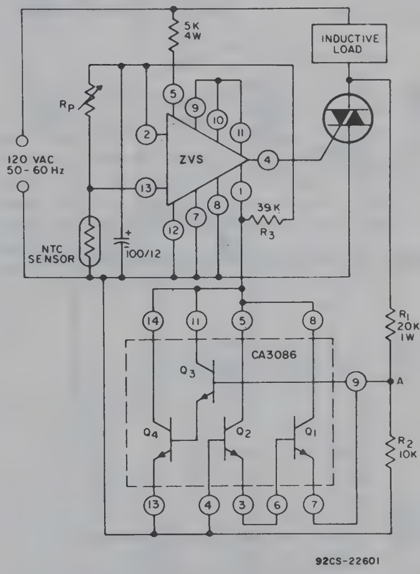


Fig. 19 – Use of the CA3058 or CA3059 together with CA3086 for switching inductive loads.

The circuit shown in Fig. 19 forms a pulse of gate current and can supply high peak drive to power traics with low average current drain on the internal supply. The gate pulse will always last just long enough to latch the thyristor so that

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Formerly RCA 40526

there is no problem with delaying the pulse to an optimum time. As in other circuits of this type, RFI results if the load is not suitably inductive because the zero-crossing detector is disabled and initial turn-on occurs at random.

The gate pulse forms because the voltage at point A when the thyristor is on is less than 1.3 volts: therefore, the output of the zero-voltage switch is inhibited, as described above. The resistor divider R_1 and R_2 should be selected to assure this condition. When the triac is on, the voltage at point A is approximately one-third of the instantaneous on-state voltage (v_T) of the thyristor. For most RCA thyristors, v_T (max) is less than 2 volts, and the divider shown is a conservative one. When the load current passes through zero, the triac commutates and turns off. Because the circuit is still being driven by the line voltage, the current in the load attempts to reverse, and voltage increases rapidly across the "turned-off" triac. When this voltage exceeds 4 volts, one portion of the CA3086 conducts and removes the inhibit signal to permit application of gate drive. Turning the triac on causes the voltage across it to drop and thus ends the gate pulse. If the latching current has not been attained, another gate pulse forms, but no discontinuity in the load current occurs.

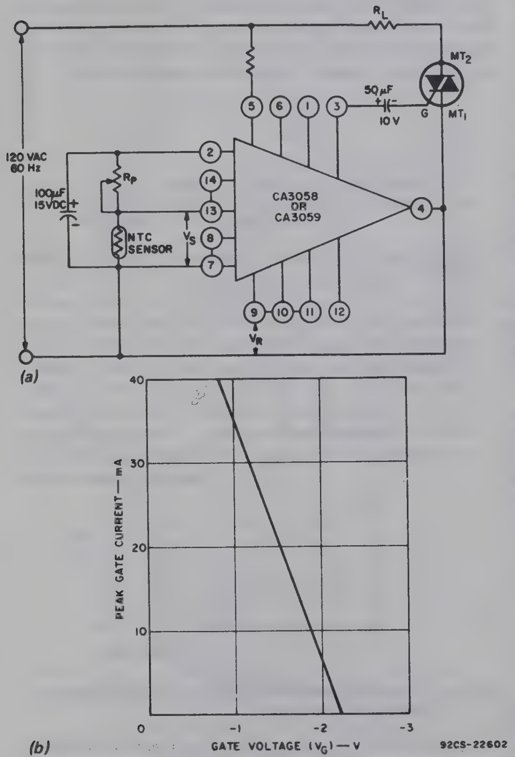

Fig. 20 – Use of the CA3058 or CA3059 to provide negative gate pulses: (a) schematic diagram; (b) peak gate current (at terminal 3) as a function of gate voltage.

Provision of Negative Gate Current

Triacs trigger with optimum sensitivity when the polarity of the gate voltage and the voltage at the main terminal 2 are similar (I^+ and II^- modes). Sensitivity is degraded when the polarities are opposite (I^- and III^+ modes). Although RCA triacs are designed and specified to have the same sensitivity in both I^- and III^+ modes, some other types have very poor sensitivity in the III^+ condition. Because the zero-voltage switch supplies positive gate pulses, it may not directly drive some higher-current triacs of these other types.

The circuit shown in Fig. 20(a) uses the negative-going voltage at terminal 3 of the zero-voltage switch to supply a negative gate pulse through a capacitor. The curve in Fig. 20(b) shows the approximate peak gate current as a function of gate voltage V_G. Pulse width is approximately 80 microseconds.

Operation with Low-Impedance Sensors

Although the zero-voltage switch can operate satisfactorily with a wide range of sensors, sensitivity is reduced when sensors with impedances greater than 20,000 ohms are used. Typical sensitivity is one per cent for a 5000-ohm sensor and increases to three per cent for a 0.1-megohm sensor.

Low-impedance sensors present a different problem. The sensor bridge is connected across the internal power supply and causes a current drain. A 5000-ohm sensor with its associated 5000-ohm series resistor draws less than 1 milliampere. On the other hand, a 300-ohm sensor draws a current of 8 to 10 milliampers from the power supply.

Fig. 21 shows the 600-ohm load line of a 300-ohm sensor on a redrawn power-supply regulation curve for the zero-voltage switch. When a 10,000-ohm series resistor is used the voltage across the circuit is less than 3 volts and both sensitivity and output current are significantly reduced. When a 5000-ohm series resistor is used, the supply voltage is nearly 5 volts, and operation is approximately normal. For more consistent operation, however, a 4000-ohm series resistor is recommended.

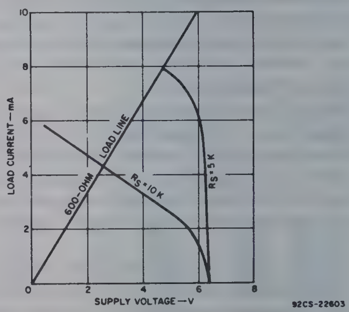

Fig. 21 – Power-supply regulation of the CA3058 or CA3059 with 300-ohm sensor (600-ohm load) for two values of serie resistor.

Although positive-temperature-coefficient (PTC) sensors rated at 5 kilohms are available, the existing sensors in ovens are usually of a much lower value. The circuit shown in Fig. 22 is offered to accommodate these inexpensive metal-wound sensors. A schematic diagram of the RCA CA3080 integrated-circuit operational transconductance amplifier used in Fig. 22, is shown in Fig. 23. With an amplifier bias current, I_{ABC}, of 100 microamperes, a forward transconductance of 2 milliohms is achieved in this configuration. The CA3080 switches when the voltage at terminal 2 exceeds the voltage at terminal 3. This action allows the sink current, I_s, to flow from terminal 13 of the zero-voltage switch (the input impedance to terminal 13 of the zero-voltage switch is approximately 50 kilohms); gate pulses are no longer applied to the triac because Q_2 of the zero-voltage switch is on. Hence, if the PTC sensor is cold, i.e., in the low resistance state, the load is energized. When the temperature of the PTC sensor increases to the desired temperature, the sensor enters the high resistance state, the voltage on terminal 2 becomes greater than that on terminal 3, and the triac switches the load off. Further cycling depends on the voltage across the sensor. Hence, very low values of sensor and potentiometer resistance can be used in conjunction with the zero-voltage switch power supply without causing adverse loading effects and impairing system performance.

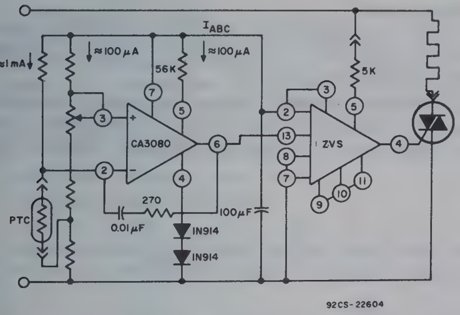
I_ABC
≈1mA
≈100µA
56K
≈100µA
5K
CA3080
ZVS
270
0.01µF
100µF
IN914
IN914
PTC
92CS-22604

Fig. 22 – Schematic diagram of circuit for use with low-resistance sensor.

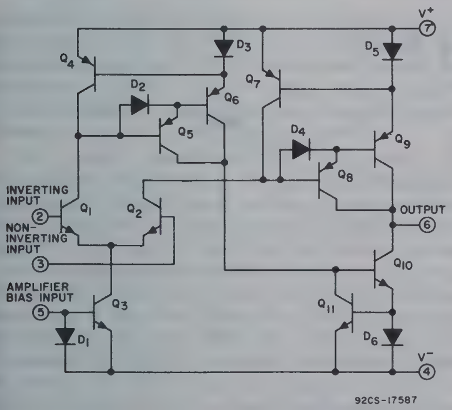
V+
D3
D5
Q4
D2
Q6
Q7
Q5
D4
Q9
Q8
INVERTING INPUT
NON-INVERTING INPUT
Q1
Q2
OUTPUT
Q10
AMPLIFIER BIAS INPUT
Q3
Q11
D1
D6
V−
92CS-17587

Fig. 23 – Schematic diagram of the CA3080.

Interfacing Techniques

Fig. 24 shows a system diagram that illustrates the role of the zero-voltage switch and thyristor as an interface between the logic circuitry and the load. There are several basic interfacing techniques. Fig. 25(a) shows the **direct input** technique. When the logic output transistor is switched from the on state (saturated) to the off state, the load will be turned on at the next zero-voltage crossing by means of the interfacing zero-voltage switch and the triac. When the logic output transistor is switched back to the on state, zero-crossing pulses from the zero-voltage switch to the triac

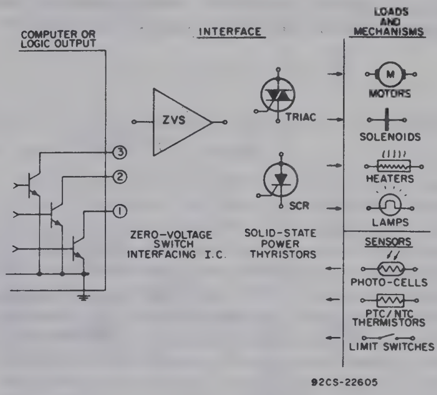
COMPUTER OR LOGIC OUTPUT
INTERFACE
LOADS AND MECHANISMS
ZVS
TRIAC
SCR
MOTORS
SOLENOIDS
HEATERS
LAMPS
SENSORS
PHOTO-CELLS
PTC/NTC THERMISTORS
LIMIT SWITCHES
ZERO–VOLTAGE SWITCH INTERFACING I.C.
SOLID-STATE POWER THYRISTORS
92CS-22605

Fig. 24 – The zero-voltage switch and thyristor as an interface.

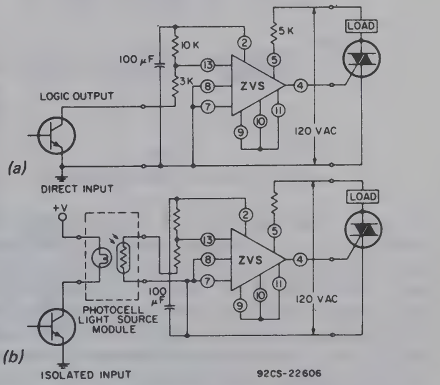
5K
LOAD
10K
100µF
3K
ZVS
LOGIC OUTPUT
120 VAC
(a)
DIRECT INPUT
+V
LOAD
ZVS
100µF
120 VAC
PHOTOCELL LIGHT SOURCE MODULE
(b)
ISOLATED INPUT
92CS-22606

Fig. 25 – Basic interfacing techniques: (a) direct input; (b) isolated input.

gate will immediately cease. Therefore, the load will be turned off when the triac commutates off as the sine-wave load current goes through zero. In this manner, both the turn-on and turn-off conditions for the load are controlled.

When electrical isolation between the logic circuit and the load is necessary, the **isolated-input** technique shown in Fig. 25(b) is used. In the technique shown, optical coupling is used to achieve the necessary isolation. The logic output transistor switches the light-source portion of the isolator. The light-sensor portion changes from a high impedance to a low impedance when the logic output transistor is switched from off to on. The light sensor is connected to the differential amplifier input of the zero-voltage switch, which senses the change of impedance at a threshold level and switches the load on as in Fig. 25(a).

Sensor Isolation

In many applications, electrical isolation of the sensor from the ac input line is desirable. Two common isolation techniques are shown in Fig. 26.

Transformer Isolation – In Fig. 26(a), a pulse transformer is used to provide electrical isolation of the sensor from incoming ac power lines. The pulse transformer T_1 isolates the

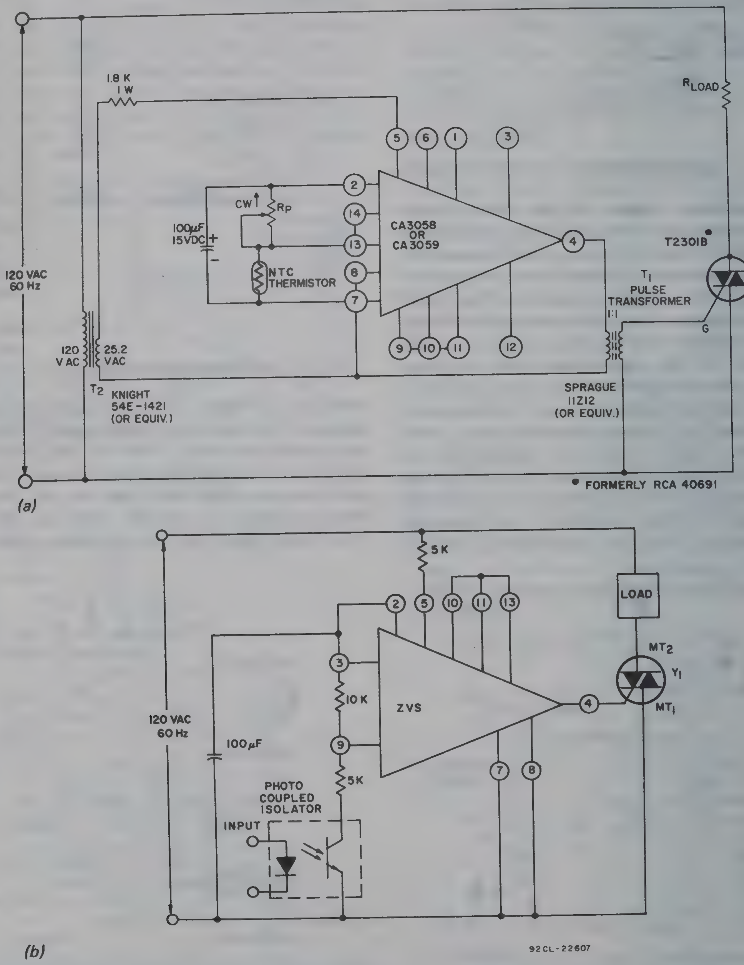
120 VAC
60 Hz
1.8 K
1 W
5
6
1
3
2
14
13
8
7
CW
RP
100µF
15VDC
+
–
NTC
THERMISTOR
CA3058
OR
CA3059
4
9
10
11
12
120
V AC
25.2
VAC
T2
KNIGHT
54E-1421
(OR EQUIV.)
RLOAD
T2301B*
MT2
Y1
MT1
G
T1
PULSE
TRANSFORMER
1:1
SPRAGUE
11Z12
(OR EQUIV.)
* FORMERLY RCA 40691
(a)
120 VAC
60 Hz
5K
2
5
10
11
13
LOAD
3
10 K
ZVS
9
100µF
5K
PHOTO
COUPLED
ISOLATOR
INPUT
7
8
4
MT2
Y1
MT1
(b)
92CL-22607

Fig. 26 – Zero-voltage switch (a) on-off controller with an isolated sensor, (b) on-off controller with photocoupler.

sensor from terminal No. 1 of the triac Y_1, and transformer T_2 isolates the CA3058 or CA3059 from the power lines. Capacitor C_1 shifts the phase of the output pulse at terminal No. 4 in order to retard the gate pulse delivered to triac Y_1 to compensate for the small phase-shift introduced by transformer T_1.

Photocoupler Isolation – In Fig. 26(b), a photocoupler provides electrical isolation of the sensor logic from the incoming ac power lines. When a logic "1" is applied at the input of the photocoupler, the triac controlling the load will be turned on whenever the line voltage passes through zero. When a logic "0" is applied to the photocoupler, the triac will turn off and remain off until a logic "1" appears at the input of the photocoupler.

TEMPERATURE CONTROLLERS

Fig. 27 shows a triac used in an on-off temperature-controller configuration. The triac is turned on at zero voltage whenever the voltage V_s exceeds the reference voltage V_r. The transfer characteristic of this system, shown in Fig. 28(a), indicates significant thermal overshoots and undershoots, a well-known characteristic of such a system. The differential or hysteresis of this system, however, can be further increased, if desired, by the addition of positive feedback.

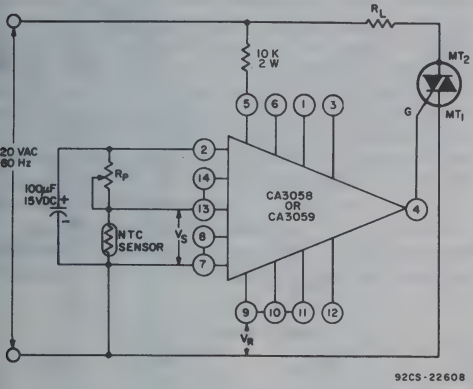

Fig. 27 – CA3058 or CA3059 on-off temperature controller.

For precise temperature-control applications, the proportional-control technique with synchronous switching is employed. The transfer curve for this type of controller is shown in Fig. 28(b). In this case, the duty cycle of the power supplied to the load is varied with the demand for heat required and the thermal time constant (inertia) of the system. For example, when the temperature setting is increased in an on-off type of controller, full power (100 per cent duty cycle) is supplied to the system. This effect results in significant temperature excursions because there is no anticipatory circuit to reduce the power gradually before the actual set temperature is achieved. However, in a proportional control technique, less power is supplied to the load (reduced duty cycle) as the error signal is reduced (sensed temperature approaches the set temperature).

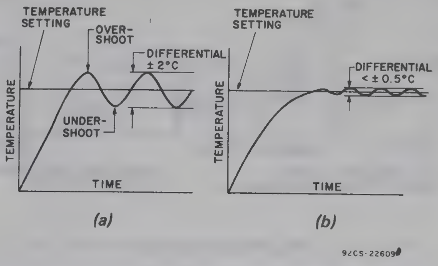

Fig. 28 – Transfer characteristics of (a) on-off and (b) proportional control systems.

Before such a system is implemented, a time base is chosen so that the on-time of the triac is varied within this time base. The ratio of the on-to-off time of the triac within this time interval depends on the thermal time constant of the system and the selected temperature setting. Fig. 29 illustrates the principle of proportional control. For this operation, power is supplied to the load until the ramp voltage reaches a value greater than the dc control signal supplied to the opposite side of the differential amplifier. The triac then remains off for the remainder of the time-base period. As a result, power is "proportioned" to the load in a direct relation to the heat demanded by the system.

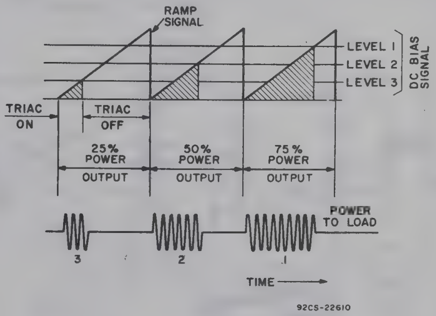

Fig. 29 – Principles of proportional control.

For this application, a simple ramp generator can be realized with a minimum number of active and passive components. A ramp having good linearity is not required for proportional operation because of the nonlinearity of the thermal system and the closed-loop type of control. In the circuit shown in Fig. 30, the ramp voltage is generated when the capacitor C_1 charges through resistors R_0 and R_1. The time base of the ramp is determined by resistors R_2 and R_3, capacitor C_2, and the breakover voltage of the D3202U* diac.

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* Formerly RCA 45412

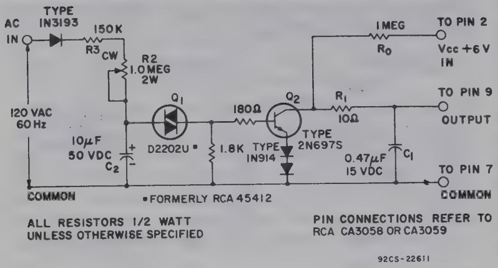

TYPE
1N3193
AC IN
150K
R3
CW
R2
1.0MEG
2W
120 VAC
60 Hz
10μF
50 VDC
C2
Q1
D2202U *
180Ω
1.8K
TYPE
1N914
Q2
TYPE
2N697S
1MEG
R0
TO PIN 2
Vcc +6 V
IN
R1
10Ω
TO PIN 9
OUTPUT
0.47μF
15 VDC
C1
TO PIN 7
COMMON
COMMON
* FORMERLY RCA 45412
ALL RESISTORS 1/2 WATT
UNLESS OTHERWISE SPECIFIED
PIN CONNECTIONS REFER TO
RCA CA3058 OR CA3059
92CS-22611

Fig. 30 – Ramp generator.

When the voltage across C_2 reaches approximately 32 volts, the diac switches and turns on the 2N697S transistor and 1N914 diodes. The capacitor C_1 then discharges through the collector-to-emitter junction of the transistor. This discharge time is the retrace or flyback time of the ramp. The circuit shown can generate ramp times ranging from 0.3 to 2.0 seconds through adjustment of R_2. For precise temperature regulation, the time base of the ramp should be shorter than the thermal time constant of the system, but long with respect to the period of the 60-Hz line voltage. Fig. 31 shows a triac connected for the proportional mode.

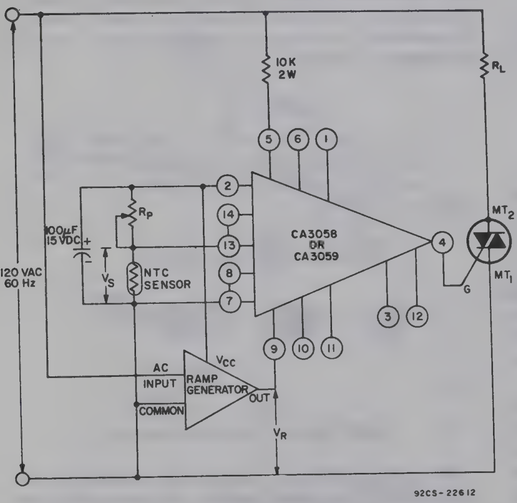

10K
2W
RL
5
6
1
2
14
13
8
7
RP
100μF
15 VDC
VS
NTC
SENSOR
120 VAC
60 Hz
CA3058
OR
CA3059
4
MT2
MT1
G
3
12
9
10
11
VCC
AC
INPUT
RAMP
GENERATOR
OUT
COMMON
VR
92CS-22612

Fig. 31 – CA3058 or CA3059 proportional temperature controller.

Fig. 32(a) shows a dual-output temperature controller that drives two triacs. When the voltage V_s developed across the temperature-sensing network exceeds the reference voltage V_{R1}, motor No. 1 turns on. When the voltage across the network drops below the reference voltage V_{R2}, motor No. 2 turns on. Because the motors are inductive, the currents I_{M1} lag the incoming line voltage. The motors, however, are switched by the triacs at zero current, as shown in Fig. 32(b).

The problem of driving inductive loads such as these motors by the narrow pulses generated by the zero-voltage switch is solved by use of the sensitive-gate RCA-40526 triac. The high sensitivity of this device (3 milliamperes maximum) and low latching current (approximately 9 milliamperes) permit synchronous operation of the temperature-controller circuit. In Fig. 32(a), it is apparent that, though the gate pulse V_g of triac Y_1 has elapsed, triac Y_2 is switched on by the current through R_{L1}. The low latching current of the RCA-40526 triac results in dissipation of only 2 watts in R_{L1}, as opposed to 10 to 20 watts when devices that have high latching currents are used.

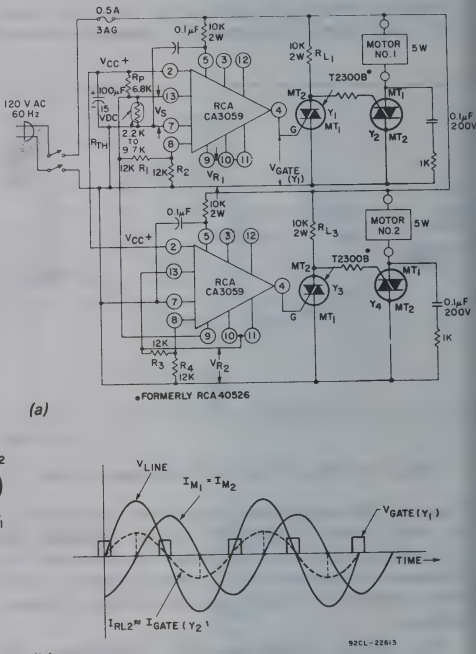

0.5A
3AG
0.1μF
10K
2W
VCC +
100μF
15
VDC
RP
6.8K
VS
2.2K
TO
9.7K
RTH
12K R1
12K R2
VR1
RCA
CA3059
120 V AC
60 Hz
10K
2W
RL1
MOTOR
NO.1
5W
T2300B*
MT2
Y1
MT1
Y2
MT2
MT1
G
VGATE (Y1)
0.1μF
200V
1K
0.1μF
10K
2W
VCC +
RCA
CA3059
10K
2W
RL3
MOTOR
NO.2
5W
T2300B*
MT2
Y3
Y4
MT1
MT2
G
0.1μF
200V
1K
12K
R3
R4
12K
VR2
* FORMERLY RCA 40526
(a)
VLINE
IM1 = IM2
VGATE (Y1)
TIME
IRL2 ≈ IGATE (Y2)
92CL-22613
(b)

Fig. 32 – Dual output, over-under temperature controller (a) circuit (b) voltage and current waveforms.

Electric-Heat Application

For electric-heating applications, the RCA-2N544 40-ampere triac and the zero-voltage switch constitute a optimum pair. Such a combination provides synchronou switching and effectively replaces the heavy-duty contacto which easily degrade as a result of pitting and wearout fro the switching transients. The salient features of the 2N544 40-ampere triac are as follows:

(1) 300-ampere single-surge capability (for operation at 0-Hz),

(2) a typical gate sensitivity of 20 milliamperes in the $I(^+)$ nd $III(^+)$ modes,

(3) low on-state voltage of 1.5 volts maximum at 0 amperes, and

(4) available V_{DROM} equal to 600 volts.

Fig. 33 shows the circuit diagram of a ynchronous-switching heat-staging controller that is used for lectric heating systems. Loads as heavy as 5 kilowatts are witched sequentially at zero voltage to eliminate RFI and revent a dip in line voltage that would occur if the full 5 kilowatts were to be switched simultaneously.

Transistor Q_1 and Q_4 are used as a constant-current source o charge capacitor C in a linear manner. Transistor Q_2 acts as a uffer stage. When the thermostat is closed, a ramp voltage is rovided at output E_o. At approximately 3-second intervals, ach 5-kilowatt heating element is switched onto the power ystem by its respective triac. When there is no further demand or heat, the thermostat opens, and capacitor C discharges hrough R_1 and R_2 to cause each triac to turn off in the everse heating sequence. It should be noted that some alf-cycling occurs before the heating element is switched fully n. This condition can be attributed to the inherent issymmetry of the triac and is further aggravated by the low-rising ramp voltage applied to one of the inputs. The iming diagram in Fig. 34 shows the turn-on and turn-off equence of the heating system being controlled.

Seemingly, the basic method shown in Fig. 33 could be odified to provide proportional control in which the number f heating elements switched into the system, under any given thermal load, would be a function of the BTU's required by the system or the temperature differential between an indoor and outdoor sensor within the total system environment. That is, the closing of the thermostat would not switch in all the heating elements within a short time interval, which inevitably results in undesired temperature excursions, but would switch in only the number of heating elements required to satisfy the actual heat load.

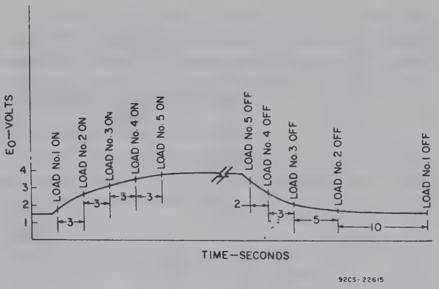
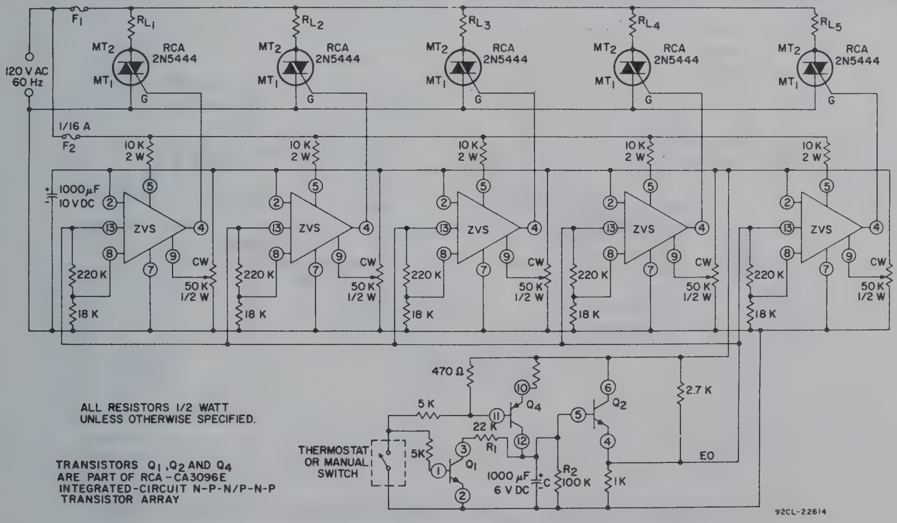


Fig. 34 – Ramp-voltage waveform for the heat-staging controller.

Oven/Broiler Control

Zero-voltage switching is demonstrated in the oven control circuit shown in Fig. 35. In this circuit, a sensor element is included in the oven to provide a closed-loop system for accurate control of the oven temperature.

As shown in Fig. 35, the temperature of the oven can be adjusted by means of potentiometer R_1, which acts, together with the sensor, as a voltage divider at terminal 13. The voltage



F1
RL1
RL2
RL3
RL4
RL5
MT2
MT1
G
RCA 2N5444
120 V AC 60 Hz
1/16 A
F2
10 K 2 W
1000 µF 10 VDC
ZVS
2
4
5
7
8
9
13
CW
220 K
18 K
50 K 1/2 W
470 Ω
5 K
22 K
R1
10
11
12
Q4
6
5
4
Q2
2.7 K
EO
THERMOSTAT OR MANUAL SWITCH
5K
1
2
3
Q1
1000 µF 6 V DC
C
R2 100 K
1K
ALL RESISTORS 1/2 WATT UNLESS OTHERWISE SPECIFIED.
TRANSISTORS Q1, Q2 AND Q4 ARE PART OF RCA-CA3096E INTEGRATED-CIRCUIT N-P-N/P-N-P TRANSISTOR ARRAY
92CL-22614

Fig. 33 – Synchronous-switching heat-staging controller using a series of zero-voltage switches.

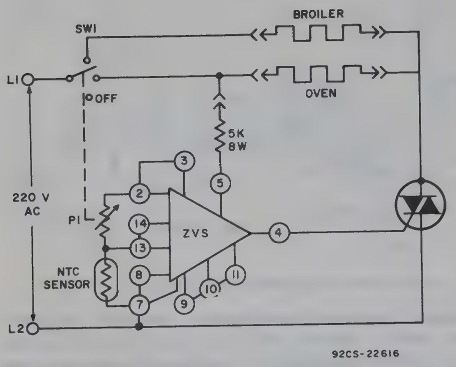


Fig. 35 – Schematic diagram of basic oven control.

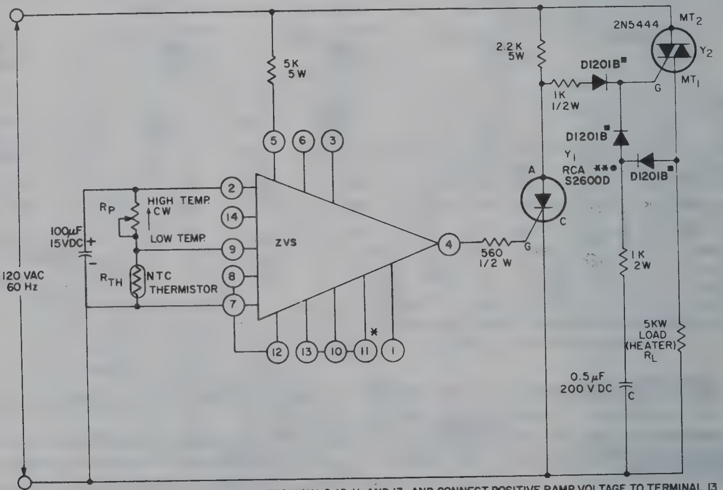
at terminal 13 is compared to the fixed bias at terminal 9 which is set by internal resistors R_4 and R_5. When the oven is cold and the resistance of the sensor is high, transistors Q_2 and Q_4 are off, a pulse of gate current is applied to the triac, and heat is applied to the oven. Conversely, as the desired temperature is reached, the bias at terminal 13 turns the triac off. The closed-loop feature then cycles the oven element on and off to maintain the desired temperature to approximately ±2°C of the set value. Also, as has been noted, external resistors between terminals 13 and 8, and 7 and 8, can be used to vary this temperature and provide hysteresis. In Fig. 11, a circuit that provides approximately 10-per-cent hysteresis is demonstrated.

In addition to allowing the selection of a hysteresis value, the flexibility of the control circuit permits incorporation of other features. A PTC sensor is readily used by interchanging terminals 9 and 13 of the circuit shown in Fig. 35 and substituting the PTC for the NTC sensor. In both cases, the sensor element is directly returned to the system ground or common, as is often desired. Terminal 9 can be connected by external resistors to provide for a variety of biasing, e.g., to match a lower-resistance sensor for which the switching-point voltage has been reduced to maintain the same sensor current.

To accommodate the self-cleaning feature, external switching, which enables both broiler and oven units to be paralleled, can easily be incorporated in the design. Of course, the potentiometer must be capable of a setting such that the sensor, which must be characterized for the high, self-clean temperature, can monitor and establish control of the high-temperature, self-clean mode. The ease with which this self-clean mode can be added makes the over-all solid-state systems cost-competitive with electromechanical systems of comparable capability. In addition, the system incorporates solid-state reliability while being neater, more easily calibrated, and containing less-costly system wiring.

Integral-Cycle Temperature Controller (No half-cycling)

If a temperature controller which is completely devoid of half-cycling and hysteresis is required, then the circuit shown in Fig. 36 may be used. This type of circuit is essential for applications in which half-cycling and the resultant dc component could cause overheating of a power transformer on the utility lines.



* FOR PROPORTIONAL OPERATION OPEN TERMINALS 10, 11, AND 13, AND CONNECT POSITIVE RAMP VOLTAGE TO TERMINAL 13

** SELECTED FOR I_{GT} =6 mA MAXIMUM.

■ FORMERLY RCA 44003

● FORMERLY RCA 40655

92CM-22617

Fig. 36 – Integral-cycle temperature controller in which half-cycling effect is eliminated.

In the integral-cycle controller, when the temperature being controlled is low, the resistance of the thermistor is high, and an output signal at terminal 4 of zero volts is obtained. The SCR (Y_1), therefore, is turned off. The triac (Y_2) is then triggered directly from the line on positive cycles of the ac voltage. When Y_2 is triggered and supplies power to the load R_L, capacitor C is charged to the peak of the input voltage. When the ac line swings negative, capacitor C discharges through the triac gate to trigger the triac on the negative half-cycle. The diode-resistor-capacitor "slaving network" triggers the triac on negative half-cycle to provide only **integral cycles** of ac power to the load.

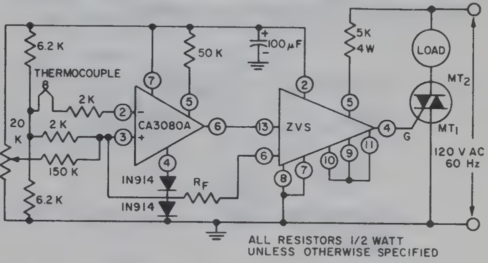
When the temperature being controlled reaches the desired value, as determined by the thermistor, then a positive voltage level appears at terminal 4 of the zero-voltage switch. The SCR then starts to conduct at the beginning of the positive input cycle to shunt the trigger current away from the gate of the triac. The triac is then turned off. The cycle repeats when the SCR is again turned OFF by the zero-voltage switch.

The circuit shown in Fig. 37 is similar to the configuration in Fig. 36 except that the protection circuit incorporated in the zero-voltage switch can be used. In this new circuit, the NTC sensor is connected between terminals 7 and 13, and transistor Q_o inverts the signal output at terminal 4 to nullify the phase reversal introduced by the SCR (Y_1). The internal power supply of the zero-voltage switch supplies bias current to transistor Q_o.

Of course, the circuit shown in Fig. 37 can readily be converted to a **true proportional integral-cycle temperature controller** simply by connection of a positive-going ramp voltage to terminal 9 (with terminals 10 and 11 open), as previously discussed in this Note.

Thermocouple Temperature Control

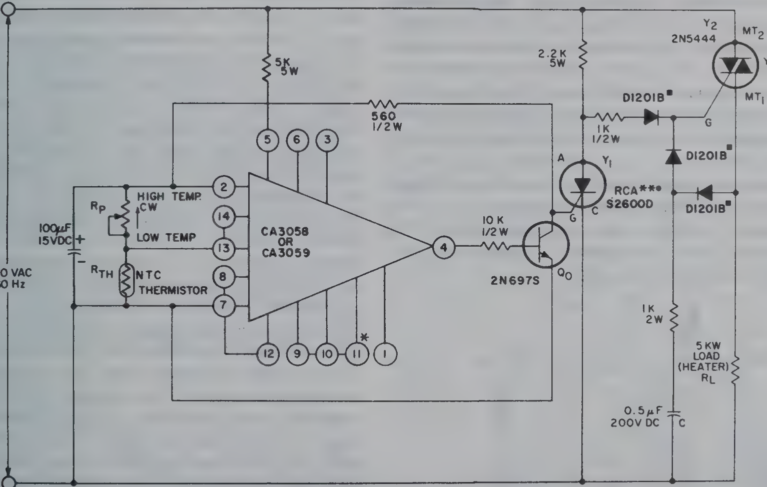
Fig. 38 shows the CA3080A operating as a pre-amplifier for the zero-voltage switch to form a zero-voltage switching circuit for use with thermocouple sensors.


6.2 K
THERMOCOUPLE
2 K
20 K
2 K
150 K
6.2 K
50 K
100 µF
CA3080A
IN914
IN914
R_F
ZVS
5K 4W
LOAD
MT2
MT1
G
120 V AC 60 Hz
2
3
4
5
6
7
13
8
9
10
11

ALL RESISTORS 1/2 WATT UNLESS OTHERWISE SPECIFIED

92CS-22619

Fig. 38 – Thermocouple temperature control with zero-voltage switching.


120 VAC 60 Hz
100µF 15VDC
5K 5W
560 1/2 W
R_P
HIGH TEMP CW
LOW TEMP
R_TH
NTC THERMISTOR
CA3058 OR CA3059
5
6
3
2
14
13
8
7
12
9
10
11
1
4
*
10 K 1/2 W
2N697S
Q_O
2.2 K 5W
Y2 2N5444
MT2
MT1
Y2
G
D1201B■
1 K 1/2 W
D1201B■
A
Y1
RCA**● S2600D
C
G
D1201B■
1 K 2 W
0.5µF 200V DC
C
5 KW LOAD (HEATER) R_L

* FOR PROPORTIONAL OPERATION OPEN TERMINALS 9,10 AND 11 AND CONNECT POSTIVE RAMP VOLTAGE TO TERMINAL 9
**SELECTED FOR I_{GT} = 6 mA MAXIMUM
■FORMERLY RCA 44003
●FORMERLY RCA 40655

92CM-22618

Fig. 37 – CA3058 or CA3059 integral-cycle temperature controller that features a protection circuit and no half-cycling effect.

MACHINE CONTROL AND AUTOMATION

The earlier section on interfacing techniques indicated several techniques of controlling ac loads through a logic system. Many types of automatic equipment are not complex enough or large enough to justify the cost of a flexible logic system. A special circuit, designed only to meet the control requirements of a particular machine, may prove more economical. For example, consider the simple machine shown in Fig. 39; for each revolution of the motor, the belt is advanced a prescribed distance, and the strip is then punched. The machine also has variable speed capability.

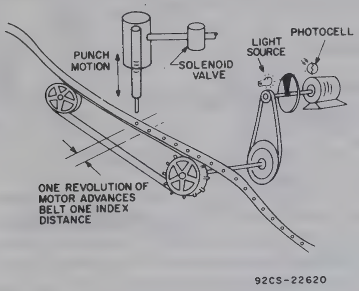


Fig. 39 – Step-and-punch machine.

The typical electromechanical control circuit for such a machine might consist of a mechanical cambank driven by a separate variable speed motor, a time delay relay, and a few logic and power relays. Assuming use of industrial-grade controls, the control system could get quite costly and large. Of greater importance is the necessity to eliminate transients generated each time a relay or switch energizes and deenergizes the solenoid and motor. Fig. 40 shows such transients, which might not affect the operation of this machine, but could affect the more sensitive solid-state equipment operating in the area.

A more desirable system would use triacs and zero-voltage switching to incorporate the following advantages:

a. Increased reliability and long life inherent in solid-state devices as opposed to moving parts and contacts associated with relays.

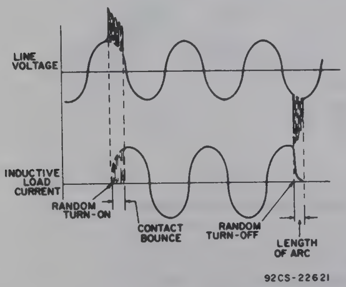


Fig. 40 – Transients generated by relay-contact bounce and non-zero turn-off of inductive load.

b. Minimized generation of EMI/RFI using zero-voltage switching techniques in conjunction with thyristors.

c. Elimination of high-voltage transients generated by relay-contact bounce and contacts breaking inductive loads, as shown in Fig. 39.

d. Compactness of the control system.

The entire control system could be on one printed-circuit board, and an over-all cost advantage would be achieved. Fig. 41 is a timing diagram for the proposed solid-state machine control, and Fig. 42 is the corresponding control schematic. A variable-speed machine repetition rate pulse is set up using either a unijunction oscillator or a transistor astable multivibrator in conjunction with a 10-millisecond one-shot multivibrator. The first zero-voltage switch in Fig. 42 is used to synchronize the entire system to zero-voltage crossing. Its output is inverted to simplify adaptation to the rest of the circuit. The center zero-voltage switch is used as an interface for the photo-cell, to control one revolution of the motor. The gate drive to the motor triac is continuous dc, starting at zero voltage crossing. The motor is initiated when both the machine rate pulse and the zero-voltage sync are at low voltage. The bottom zero-voltage switch acts as a time-delay for pulsing the solenoid. The inhibit input, terminal 1, is used to assure that the solenoid will not be operated while the motor is running. The time delay can be adjusted by varying the reference level (50K potentiometer) at terminal 13 relative to the capacitor charging to that level on terminal 9. The capacitor is reset by the SCR during the motor operation. The gate drive to the solenoid triac is direct current. Direct current is used to trigger both the motor and solenoid triacs because it is the most desirable means of switching a triac into an inductive load. The output of the zero-voltage switch will be continuous dc by connecting terminal 12 to common. The output under dc operation should be limited to 20 milliamperes. The motor triac is synchronized to zero crossing because it is a high-crurent inductive load and there is a chance of generating RFI. The solenoid is a very low current inductive load, so there would be little chance of generating RFI: therefore, the initial triac turn-on can be random, which simplifies the circuitry.

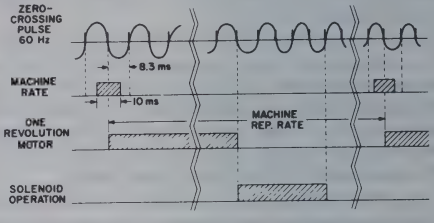


Fig. 41 – Timing diagram for proposed solid-state machine control.

This example shows the versatility and advantages of the RCA zero-voltage switch used in conjunction with triacs as interfacing and control elements for machine control.

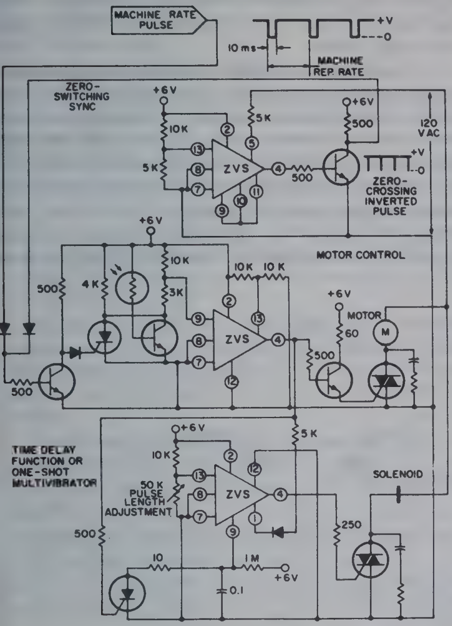

MACHINE RATE PULSE
+V
0
10 ms
MACHINE REP. RATE
ZERO-SWITCHING SYNC
+6V
10K
5K
ZVS
+6V
500
500
120 VAC
ZERO-CROSSING INVERTED PULSE
+6V
10K
3K
4K
500
10K 10 K
MOTOR CONTROL
+6V
MOTOR
M
60
500
500
TIME DELAY FUNCTION OR ONE-SHOT MULTIVIBRATOR
+6V
10K
50 K PULSE LENGTH ADJUSTMENT
5K
SOLENOID
250
500
10
1 M
+6V
0.1
92CS-22623

Fig. 42 – Schematic of proposed solid-state machine control.

00-Hz TRIAC APPLICATIONS

The increased complexity of aircraft control systems, and he need for greater reliability than electromechanical witching can offer, has led to the use of solid-state power witching in aircraft. Because 400-Hz power is used almost niversally in aircraft systems, RCA offers a complete line of riacs rated for 400-Hz applications. Use of the RCA ero-voltage switch in conjunction with these 400-Hz triacs esults in a minimum of RFI, which is especially important in ircraft.

Areas of application for 400-Hz triacs in aircraft include:

a. Heater controls for food-warming ovens and for windshield defrosters.
b. Lighting controls for instrument panels and cabin illumination
c. Motor controls
d. Solenoid controls
e. Power-supply switches

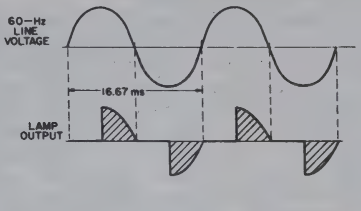


Fig. 43 – Waveforms for 60-Hz phase-controlled lamp dimmer.

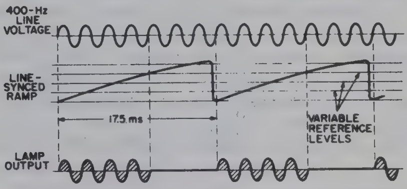


Fig. 44 – Waveforms for 400-Hz zero-voltage-switched lamp dimmer.

Lamp dimming is a simple triac application that lemonstrates an advantage of 400-Hz power over 60-Hz ower. Fig. 43 shows the adjustment of lamp intensity by hase control of the 60-Hz line voltage. RFI is generated by he step functions of power each half cycle, requiring xtensive filtering. Fig. 44 shows a means of controlling power o the lamp by the zero-voltage-switching technique. Use of 00-Hz power makes possible the elimination of complete or alf cycles within a period (typically 17.5 milliseconds) without noticeable flicker. Fourteen different levels of lamp intensity can be obtained in this manner. A line-synced ramp is set up with the desired period and applied to terminal No. 9 of the differential amplifier within the zero-voltage switch, as shown in Fig. 45. The other side of the differential amplifier (terminal No. 13) uses a variable reference level, set by the 50K potentiometer. A change of the potentiometer setting changes the lamp intensity.

In 400-Hz applications it may be necessary to widen and shift the zero-voltage switch output pulse (which is typically 12 microseconds wide and centered on zero voltage crossing), to assure that sufficient latching current is available. The 4K resistor (terminal No. 12 to common) and the 0.015-microfarad capacitor (terminal No. 5 to common) are used for this adjustment.

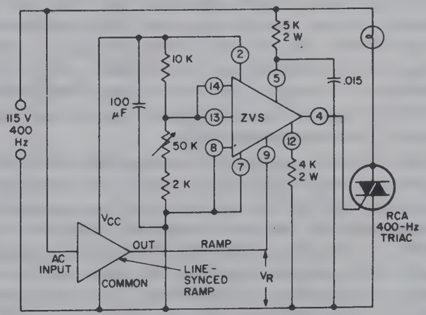
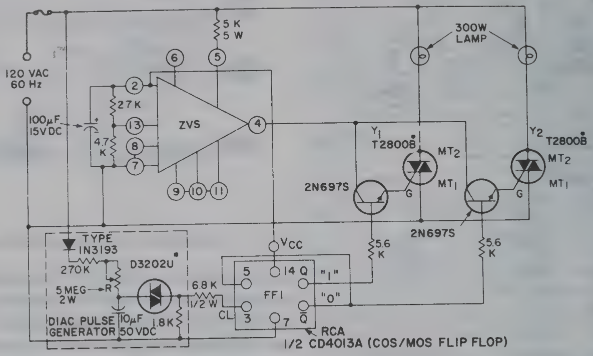

5 K 2 W
10 K
.015
115 V 400 Hz
100 μF
ZVS
50 K
2 K
4 K 2 W
RCA 400-Hz TRIAC
VCC
OUT
RAMP
AC INPUT
COMMON
LINE-SYNCED RAMP
VR
92CS-22626

Fig. 45 – Circuit diagram for 400-Hz zero-voltage-switched lamp dimmer.

SOLID-STATE TRAFFIC FLASHER

Another application which illustrates the versatility of the zero-voltage switch, when used with RCA thyristors, involves switching traffic-control lamps. In this type of application, it is essential that a triac withstand a current surge of the lamp load on a continuous basis. This surge results from the difference between the cold and hot resistance of the tungsten filament. If it is assumed that triac turn-on is at 90 degrees from the zero-voltage crossing, the first current-surge peak is approximately ten times the peak steady-state value or fifteen times the steady-state rms value. The second current-surge peak is approximately four times the steady-state rms value.



■ FORMERLY RCA 45412
• FORMERLY RCA 40668

92CM-22627

Fig. 46 – Synchronous-switching traffic flasher.

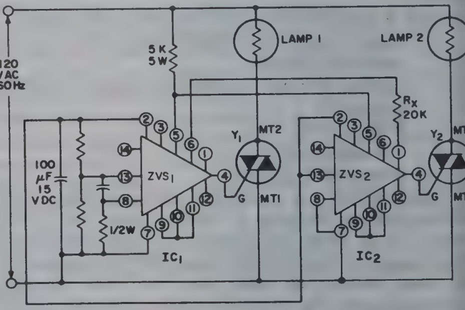
When the triac randomly switches the lamp, the rate of current rise di/dt is limited only by the source inductance. The triac di/dt rating may be exceeded in some power systems. In many cases, exceeding the rating results in excessive current concentrations in a small area of the device which may produce a hot spot and lead to device failure. Critical applications of this nature require adequate drive to the triac gate for fast turn-on. In this case, some inductance may be required in the load circuit to reduce the initial magnitude of the load current when the triac is passing through the active region. Another method may be used which involves the switching of the triac at zero line voltage. This method involves the supply of pulses to the triac gate only during the presence of zero voltage on the ac line.

Fig. 46 shows a circuit in which the lamp loads are switched at zero line voltage. This approach reduces the initial di/dt, decreases the required triac surge-current ratings, increases the operating lamp life, and eliminates RFI problems. This circuit consists of two triacs, a flip-flop (FF-1), the zero-voltage switch, and a diac pulse generator. The flashing rate in this circuit is controlled by potentiometer R, which provides between 10 and 120 flashes per minute. The state of FF-1 determines the triggering of triacs Y_1 or Y_2 by the output pulses at terminal 4 generated by the zero-crossing circuit. Transistors Q_1 and Q_2 inhibit these pulses to the gates of the triacs until the triacs turn on by the logical "1" (V_{CC} high) state of the flip-flop.

The arrangement described can also be used for a synchronous, sequential traffic-controller system by addition of one triac, one gating transistor, a "divide-by-three" logic circuit, and modification in the design of the diac pulse generator. Such a system can control the familiar red, amber, and green traffic signals that are found at many intersections.

SYNCHRONOUS LIGHT FLASHER

Fig. 47 shows a simplified version of the synchronous-switching traffic light flasher shown in Fig. 46. Flash rate is set by use of the curve shown in Fig. 16. If a mor precise flash rate is required, the ramp generator describe previously may be used. In this circuit, ZVS_1 is the maste control unit and ZVS_2 is slaved to the output of ZVS through its inhibit terminal (terminal 1). When power i applied to lamp No. 1, the voltage of terminal 6 on ZVS_1 i high and ZVS_2 is inhibited by the current in R_x. When lam



92CS-22628

Fig. 47 – Synchronous light flasher.

No. 1 is off, ZVS_2 is not inhibited, and triac Y_2 can fire. The power supplies operate in parallel. The on-off sensing amplifier in ZVS_2 is not used.

TRANSIENT-FREE SWITCH CONTROLLERS

The zero-voltage switch can be used as a simple solid-state switching device that permits ac currents to be turned on or off with a minimum of electrical transients and circuit noise.

The circuit shown in Fig. 48 is connected so that, after the control terminal 14 is opened, the electronic logic waits until the power-line voltage reaches a zero crossing before power is applied to the load Z_L. Conversely, when the control terminals are shorted, the load current continues until it reaches a zero crossing. This circuit can switch a load at zero current whether it is resistive or inductive.

The circuit shown in Fig. 49 is connected to provide the opposite control logic to that of the circuit shown in Fig. 48. That is, when the switch is closed, power is supplied to the load, and when the switch is opened, power is removed from the load.

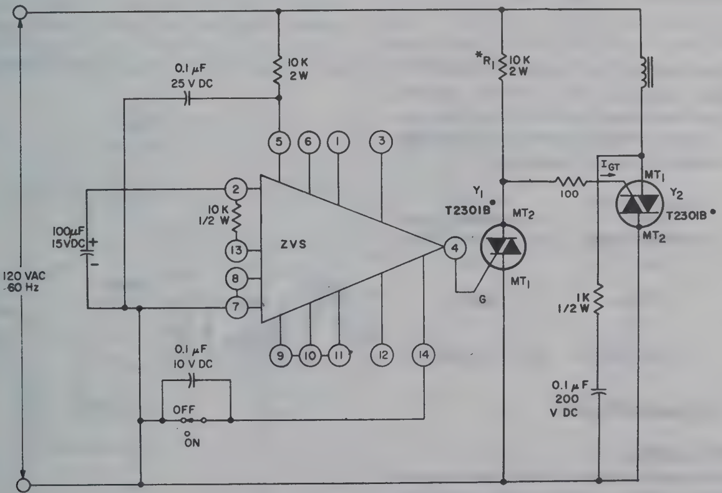
In both configurations, the maximum rms load current that can be switched depends on the rating of triac Y_2. If Y_2 is an RCA-2N5444 triac, an rms current of 40 amperes can be switched.

DIFFERENTIAL COMPARATOR FOR INDUSTRIAL USE

Differential comparators have found widespread use as limit detectors which compare two analog input signals and provide a go/no-go, logic ' one" or logic "zero" output, depending upon the relative magnitudes of these signals. Because the signals are often at very low voltage levels and very accurate discrimination is normally required between them, differential comparators in many cases employ differential amplifiers as a basic building block. However, in many industrial control applications, a high-performance differential comparator is not required. That is, high resolution, fast switching speed, and similar features are not essential. The zero-voltage switch is ideally suited for use in such applications. Connection of terminal 12 to terminal 7 inhibits the zero-voltage threshold detector of the zero-voltage switch, and the circuit becomes a differential comparator.

Fig. 50 shows the circuit arrangement for use of the zero-voltage switch as a differential comparator. In this application, no external dc supply is required, as is the case with most commercially available integrated-circuit comparators; of course, the output-current capability of the zero-voltage switch is reduced because the circuit is operating in the dc mode. The 1000-ohm resistor R_G, connected between terminal 4 and the gate of the triac, limits the output current to approximately 3 milliamperes.

When the zero-voltage switch is connected in the dc mode, the drive current for terminal 4 can be determined from a curve of the external load current as a function of dc voltage from terminals 2 and 7. This curve is shown in the technical bulletin for RCA integrated-circuit zero-voltage switches, File No. 490. Of course, if additional output current is required, an external dc supply may be connected between terminals 2

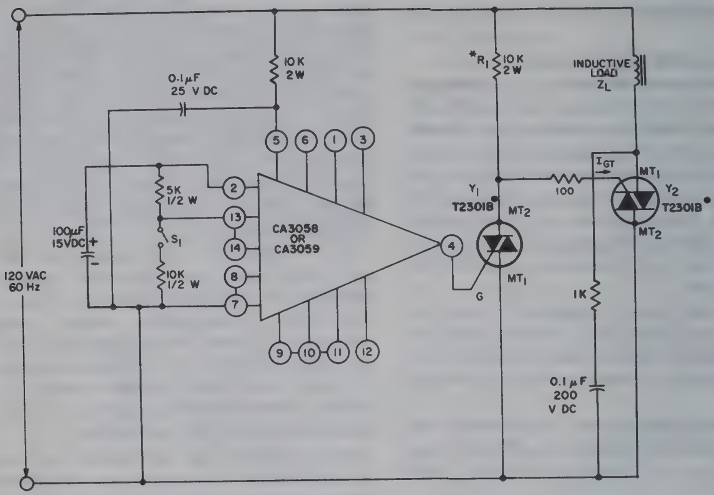


*IF Y_2, FOR EXAMPLE, IS A 40-AMPERE TRIAC, THEN R_1 MUST BE DECREASED TO SUPPLY SUFFICIENT I_{GT} FOR Y_2.

• FORMERLY RCA 40691

92CM-22629

Fig. 48 – Zero-voltage switch transient-free switch controller in which power is supplied to the load when the switch is open.


10 K
2 W
0.1 µF
25 V DC
5
6
1
3
5K
1/2 W
2
13
S1
14
8
7
10K
1/2 W
100µF
15VDC
+
120 VAC
60 Hz
CA3058
OR
CA3059
4
9
10
11
12
*R1
10 K
2 W
INDUCTIVE LOAD
ZL
IGT
MT1
Y1
T2301B
MT2
100
Y2
T2301B
MT2
MT1
G
1K
0.1 µF
200
V DC

*IF Y_2, FOR EXAMPLE, IS A 40-AMPERE TRIAC, R_1 MUST BE DECREASED TO SUPPLY SUFFICIENT I_{GT} FOR Y_2.

● FORMERLY RCA 40691

92CM-22630

Fig. 49 – Zero-voltage switch transient-free switch controller in which power is applied to the load when the switch is closed.

and 7, and resistor R_X (shown in Fig. 50) may be removed.

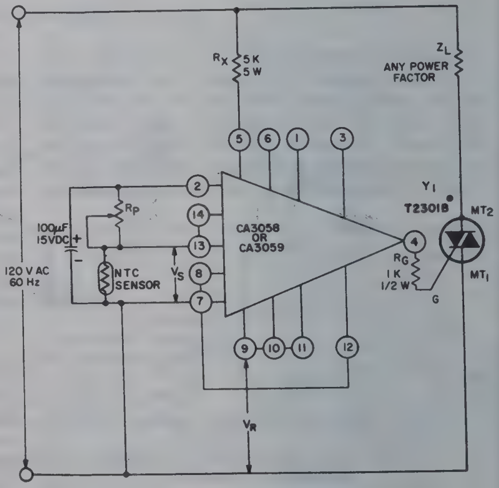
The chart below compares some of the operating characteristics of the zero-voltage switch, when used as a comparator, with a typical high-performance commercially available integrated-circuit differential comparator.

Parameters	Zero-Voltage Switch (Typical Values)	Typical Integrated-Circuit Comparator (710)
Sensitivity	30 mV	2 mV
Switching speed (rise time)	> 20 µs	90 ns
Output drive capability	*4.5 V at ≤ 4 mA	3.2 V at ≤ 5.0 mA

* Refer to Fig. 20; R_X equals 5000 ohms.

POWER ONE-SHOT CONTROL

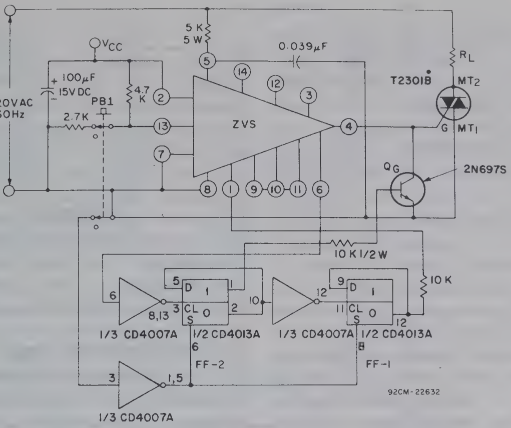
Fig.51 shows a circuit which triggers a triac for one complete half-cycle of either the positive or negative alternation of the ac line voltage. In this circuit, triggering is initiated by the push button PB-1, which produces triggering of the triac near zero voltage even though the button is randomly depressed during the ac cycle. The triac does not trigger again until the button is released and again depressed. This type of logic is required for the solenoid drive of electrically operated stapling


RX
5 K
5 W
ZL
ANY POWER FACTOR
5
6
1
3
2
14
13
8
7
Rp
100µF
15VDC
+
120 V AC
60 Hz
NTC SENSOR
VS
CA3058
OR
CA3059
4
Y1
T2301B
MT2
RG
1 K
1/2 W
MT1
G
9
10
11
12
VR

● FORMERLY RCA 40691

92CS-22631

Fig. 50 – Differential comparator using the CA3058 or CA3059 integrated-circuit zero-voltage switch.


120VAC
60Hz
Vcc
+ 100μF
15V DC
4.7 K
PB1
2.7K
5 K
5 W
0.039μF
ZVS
T2301B
RL
MT2
G
MT1
QG
2N697S
10 K 1/2 W
10 K
D
CL
S
FF-2
FF-1
1/3 CD4007A
1/2 CD4013A
92CM-22632

• FORMERLY RCA 40691

Fig. 51 – Block diagram of a power one-shot control using a zero-voltage switch.

guns, impulse hammers, and the like, where load-current flow is required for only one complete half-cycle. Such logic can also be adapted to keyboard consoles in which contact bounce produces transmission of erroneous information.

In the circuit of Fig. 51, before the button is depressed, both flip-flop outputs are in the "zero" state. Transistor Q_G is biased on by the output of flip-flop FF-1. The differential comparator which is part of the zero-voltage switch is initially biased to inhibit output pulses. When the push button is depressed, pulses are generated, but the state of Q_G determines the requirement for their supply to the triac gate. The first pulse generated serves as a "framing pulse" and does not trigger the triac but toggles FF-1. Transistor Q_G is then turned off. The second pulse triggers the triac and FF-1 which, in turn, toggles the second flip-flop FF-2. The output of FF-2 turns on transistor Q_7, as shown in Fig. 52, which inhibits all further output pulses. When the pushbutton is released, the circuit resets itself until the process is repeated with the button. Fig. 53 shows the timing diagram for the described operating sequence.

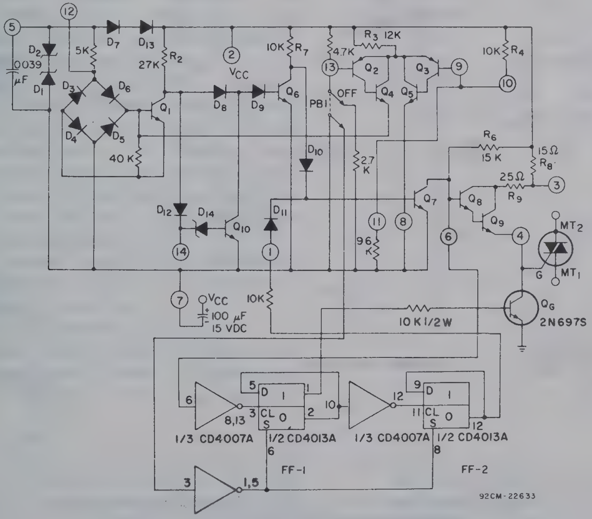

D2
.0039 μF
D1
5K
D3
D6
D4
D5
40 K
D7
D13
27K
R2
Q1
D8
D9
Vcc
10K R7
Q6
PB1
OFF
D10
4.7K
R3 12K
Q2
Q3
Q4
Q5
10K R4
2.7 K
R6
15 K
15Ω
R8
25Ω
R9
Q7
Q8
Q9
D12
D14
Q10
D11
96 K
MT2
G
MT1
Vcc
100 μF
15 VDC
10K
10 K 1/2 W
QG
2N697S
FF-1
FF-2
1/3 CD4007A
1/2 CD4013A
92CM-22633

Fig. 52 – Circuit diagram for the power one-shot control.

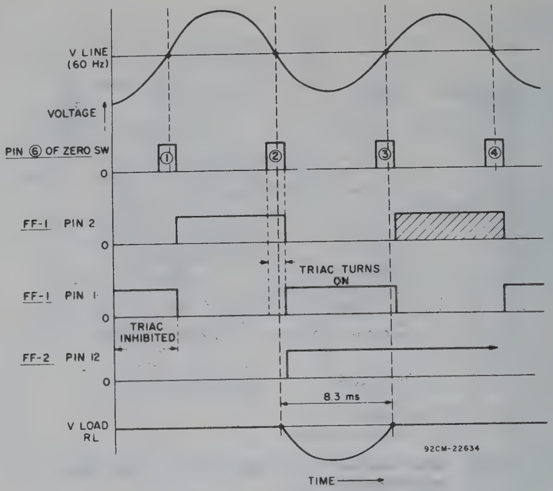
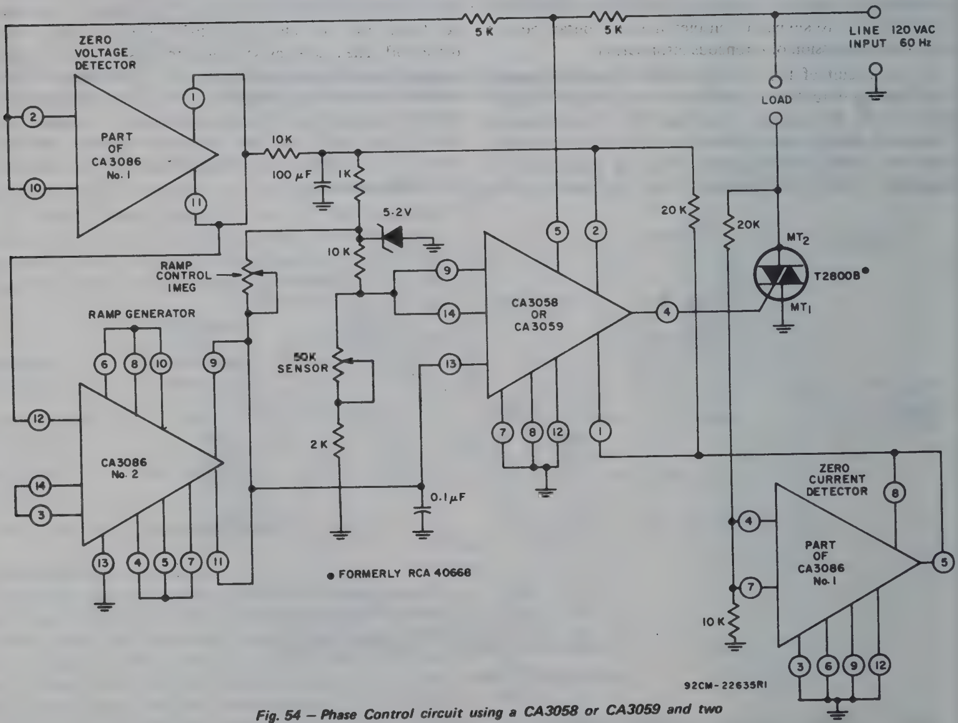


Fig. 53 – Timing diagram for the power one-shot control.


5 K
5 K
LINE INPUT
120 VAC 60 Hz
LOAD
ZERO VOLTAGE DETECTOR
PART OF CA3086 No. 1
10K
100 μF
1K
5.2V
10 K
RAMP CONTROL 1MEG
RAMP GENERATOR
CA3086 No. 2
50K SENSOR
2 K
0.1 μF
CA3058 OR CA3059
20 K
20K
MT2
T2800B●
MT1
ZERO CURRENT DETECTOR
PART OF CA3086 No. 1
10 K
92CM-22635R1

● FORMERLY RCA 40668

Fig. 54 – Phase Control circuit using a CA3058 or CA3059 and two CA3086 integrated-circuits.

PHASE CONTROL CIRCUIT

Fig. 54 shows a circuit using a CA3058 or CA3059 zero-voltage switch together with two CA3086 integrated-circuit transistor arrays to form a phase-control circuit. This circuit is specifically designed for speed control of ac induction motors, but may also be used as a light dimmer. The circuit, which can be operated from a line frequency of 50-Hz to 400-Hz, consists of a zero-voltage detector, a line-synchronized ramp generator, a zero-current detector, and a line-derived control circuit (i.e., the zero-voltage switch). The zero-voltage detector (part of CA3086 No. 1) and the ramp generator (CA3086 No. 2) provide a line-synchronized ramp-voltage output to terminal 13 of the zero-voltage switch. The ramp voltage, which has a starting voltage of 1.8 volts, starts to rise after the line voltage passes the zero point. The ramp generator has an oscillation frequency of twice the incoming line frequency. The slope of the ramp voltage can be adjusted by variation of the resistance of the 1-megohm ramp-control potentiometer. The output phase can be controlled easily to provide 180° firing of the triac by programming the voltage at terminal 9 of the zero-voltage switch. The basic operation of the zero-voltage switch driving a thyristor with an inductive load was explained previously in the discussion on switching of inductive loads.

TRIAC POWER CONTROLS FOR THREE-PHASE SYSTEMS

This section describes recommended configurations for power-control circuits intended for use with both inductive and resistive balanced three-phase loads. The specific design requirements for each type of loading condition are discussed.

In the power-control circuits described, the integrated-circuit zero-voltage switch is used as the trigger circuit for the power triacs. The following conditions are also imposed in the design of the triac control circuits:

1. The load should be connected in a three-wire configuration with the triacs placed external to the load; eiter delta or wye arrangements may be used. Four-wire loads in wye configurations can be handled as three independent single-phase systems. Delta configurations in which a triac is connected within each phase rather than in the incoming lines can also be handled as three independent single-phase systems.
2. Only one logic command signal is available for the control circuits. This signal must be electrically isolated from the three-phase power system.
3. Three separate triac gating signals are required.
4. For operation with resistive loads, the zero-voltage switching technique should be used to minimize any radio-frequency interference (RFI) that may be generated.

Isolation of DC Logic Circuitry

As explained earlier under **Special Application Considerations**, isolation of the dc logic circuitry* from the ac line, the triac, and the load circuit is often desirable even in many single-phase power-control applications. In control circuits for polyphase power systems, however, this type of isolation is essential, because the common point of the dc logic circuitry cannot be referenced to a common line in all phases.

In the three-phase circuits described in this section, photo-optic techniques (i.e., photo-coupled isolators) are used to provide the electrical isolation of the dc logic command signal from the ac circuits and the load. The photo-coupled isolators consist of an infrared light-emitting diode aimed at a silicon photo transistor, coupled in a common package. The light-emitting diode is the input section, and the photo transistor is the output section. The two components provide a voltage isolation typically of 1500 volts. Other isolation techniques, such as pulse transformers, magnetoresistors, or reed relays, can also be used with some circuit modifications.

Resistive Loads

Fig. 55 illustrates the basic phase relationships of a balanced three-phase resistive load, such as may be used in heater applications, in which the application of load power is

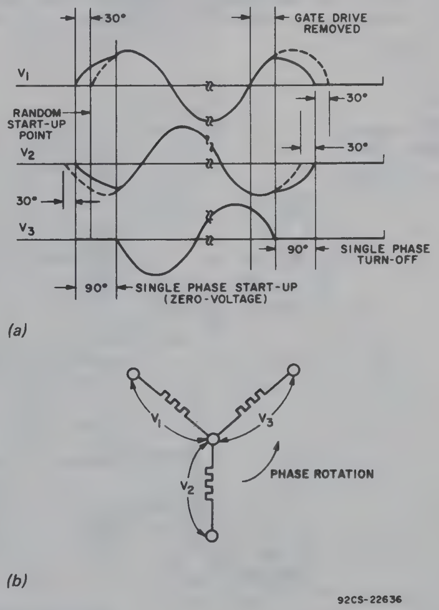


Fig. 55.– Voltage phase relationship for a three-phase resistive load when the application of load power is controlled by zero-voltage switching: (a) voltage waveforms, (b) load-circuit orientation of voltages. (The dashed lines indicate the normal relationship of the phases under steady-state conditions. The deviation at start-up and turn-off should be noted.)

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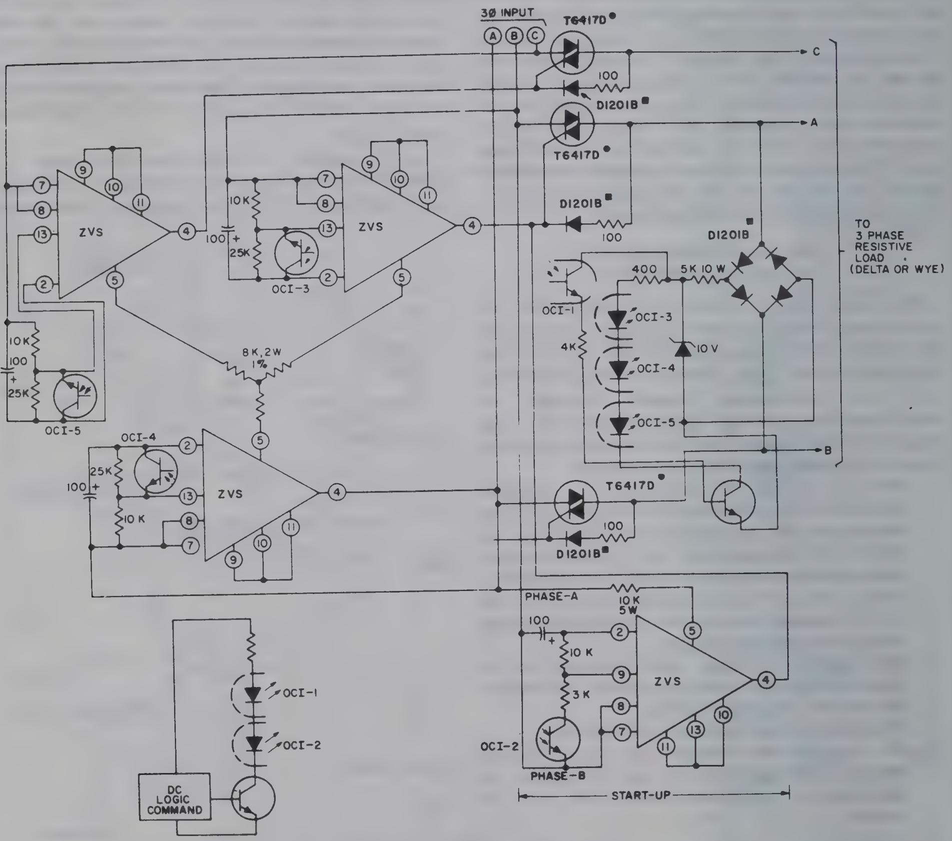
* The dc logic circuitry provides the low-level electrical signal that dictates the state of the load. For temperature controls, the dc logic circuitry includes a temperature sensor for feedback. The RCA integrated-circuit zero-voltage switch, when operated in the dc mode with some additional circuitry, can replace the dc logic circuitry for temperature controls.

single-phase, 2-wire, line-to-line circuit, comprised of phases A and B. The logic command engages the single-phase start-up zero-voltage switch and three-phase photo-coupled isolators OC13, OC14, OC15 through the photo-coupled isolators OC11 and OC12. The single-phase zero-voltage switch, which is synchronized to phases A and B, starts the system at zero voltage. As soon as start-up is accomplished, the three photo-coupled isolators OC13, OC14, and OC15 take control, and three-phase synchronization begins. When the "logic command" is turned off, all control is ended, and the triacs automatically turn off when the sine-wave current decreases to zero. Once the first phase turns off, the other two will turn off simultaneously, 90° later, as a single-phase line-to-line circuit, as is apparent from Fig. 55.

Inductive Loads

For inductive loads, zero-voltage turn-on is not generally required because the inductive current cannot increase instantaneously; therefore, the amount of RFI generated is usually negligible. Also, because of the lagging nature of the inductive current, the triacs cannot be pulse-fired at zero voltage. There are several ways in which the zero-voltage switch may be interfaced to a triac for inductive-load applications. The most direct approach is to use the zero-voltage switch in the dc mode, i.e., to provide a continuous dc output instead of pulses at points of zero-voltage crossing. This mode of operation is accomplished by connection of terminal 12 to terminal 7, as shown in Fig. 58. The output of the zero-voltage switch should also be



3Ø INPUT
A
B
C
T6417D ●
100
D1201B ■
T6417D ●
D1201B ■
100
D1201B ■
400
5K 10 W
10 V
4K
OCI-1
OCI-3
OCI-4
OCI-5
TO 3 PHASE RESISTIVE LOAD (DELTA OR WYE)
ZVS
10K
100
25K
OCI-3
8 K, 2W 1%
OCI-5
OCI-4
T6417D ●
100
D1201B ■
PHASE-A
10 K 5 W
100
10 K
3 K
OCI-2
PHASE-B
START-UP
OCI-1
OCI-2
DC LOGIC COMMAND

■ FORMERLY RCA 44003
● FORMERLY RCA 40708

92CL-22638

Fig. 57 – Three-phase power control that employs zero-voltage synchronous switching both for steady-state operation and for starting.

controlled by zero-voltage switching. The following conditions are inherent in this type of application:

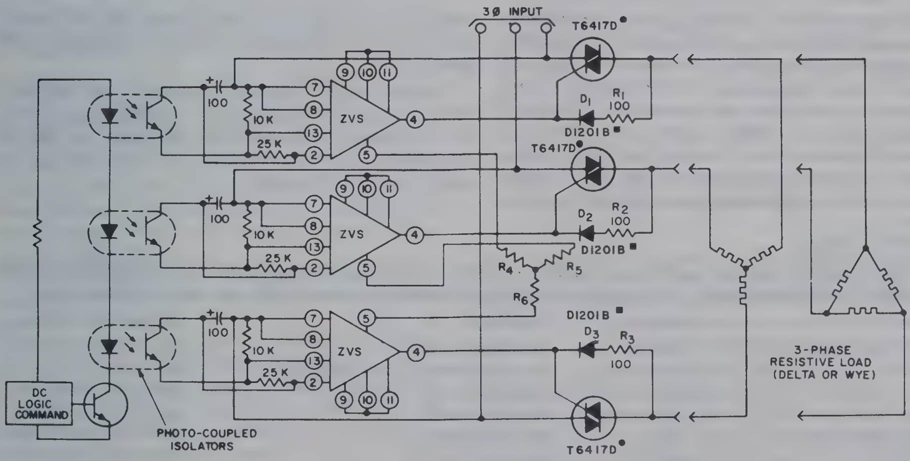
1. The phases are 120 degrees apart; consequently, all three phases cannot be switched on simultaneously at zero voltage.
2. A single phase of a wye configuration type of three-wire system cannot be turned on.
3. Two phases must be turned on for initial starting of the system. These two phases form a single-phase circuit which is out of phase with both of its component phases. The single-phase circuit leads one phase by 30 degrees and lags the other phase by 30 degrees.

These conditions indicate that in order to maintain a system in which no appreciable RFI is generated by the switching action from initial starting through the steady-state operating condition, the system must first be turned on, by zero-voltage switching, as a single-phase circuit and then must revert to synchronous three-phase operation.

Fig. 56 shows a simplified circuit configuration of a three-phase heater control that employs zero-voltage synchronous switching in the steady-state operating condition, with random starting. In this system, the logic command to turn on the system is given when heat is required, and the command to turn off the system is given when heat is not required. Time proportioning heat control is also possible through the use of logic commands.

The three photo-coupled inputs to the three zero-voltage switches change state simultaneously in response to a "logic command". The zero-voltage switches then provide a positive pulse, approximately 100 microseconds in duration, only at a zero-voltage crossing relative to their particular phase. A balanced three-phase sensing circuit is set up with the three zero-voltage switches each connected to a particular phase on their common side (terminal 7) and referenced at their high side (terminal 5), through the current-limiting resistors R4, R5, and R6, to an established artificial neutral point. This artificial neutral point is electrically equivalent to the inaccessible neutral point of the wye type of three-wire load and, therefore, is used to establish the desired phase relationships. The same artificial neutral point is also used to establish the proper phase relationships for a delta type of three-wire load. Because only one triac is pulsed on at a time, the diodes (D1, D2, and D3) are necessary to trigger the opposite-polarity triac, and, in this way, to assure initial latching-on of the system. The three resistors (R1, R2, and R3) are used for current limiting of the gate drive when the opposite-polarity triac is triggered on by the line voltage.

In critical applications that require suppression of all generated RFI, the circuit shown in Fig. 57 may be used. In addition to synchronous steady-state operating conditions, this circuit also incorporates a zero-voltage starting circuit. The start-up condition is zero-voltage synchronized to a



■ FORMERLY RCA 44003
● FORMERLY RCA 40708

92CS-22637

Fig. 56 – Simplified diagram of a three-phase heater control that employs zero-voltage synchronous switching in the steady-state operating conditions.

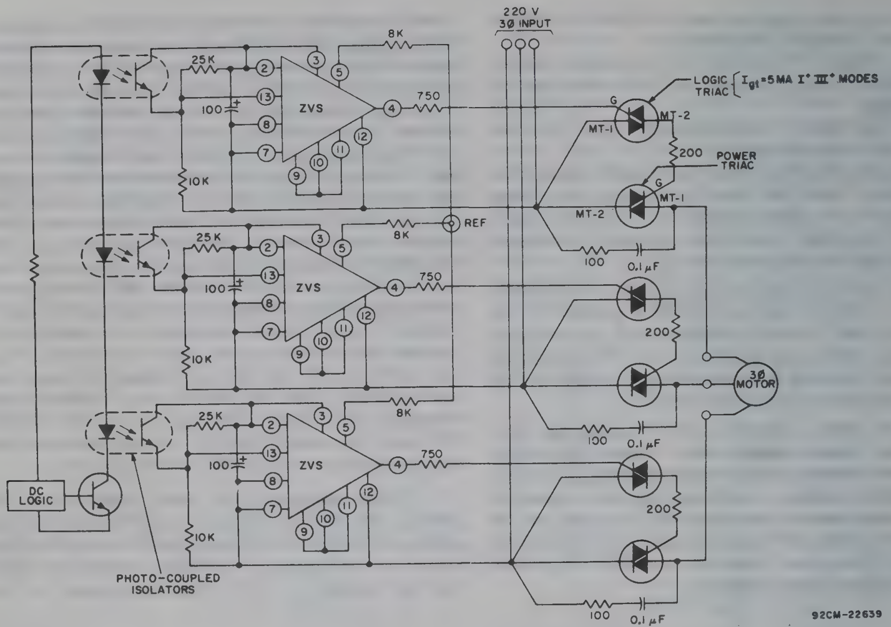


Fig. 58 – Triac three-phase control circuit for an inductive load, i.e., three-phase motor.

limited to approximately 5 milliamperes in the dc mode by the 750-ohm series resistor. Use of a triac such as the T2301D* is recommended for this application. Terminal 3 is connected to terminal 2 to limit the steady-state power dissipation within the zero-voltage switch. For most three-phase inductive load applications, the current-handling capability of the 40692 triac (2.5 amperes) is not sufficient. Therefore, the 40692 is used as a trigger triac to turn on any other currently available power triac that may be used. The trigger triac is used only to provide trigger pulses to the gate of the power triac (one pulse per half cycle); the power dissipation in this device, therefore, will be minimal.

Simplified circuits using pulse transformers and reed relays will also work quite satisfactorily in this type of application. The RC networks across the three power triacs are used for suppression of the commutating dv/dt when the circuit operates into inductive loads.

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* Formerly RCA 40692

The specific integrated-circuits, triacs, SCR's, and rectifiers included in circuit diagrams shown in this Application Note are listed below. Additional information on these devices can be obtained by requesting the applicable RCA data-bulletin file number.

Type No.	File No.	Type No.	File No.
CA3058, CA3059, and CA3079	490	T2300B (40526)	470
CA3099E	620	T2301B (40691), T2301D (40692)	431
CA3086	483	T64170 (40708)	406
CA3080	475	S2600D (40655)	496
CD4007A, CD4013A	479	D1201B (44003)	495
2N5444	456	D3202U (45412)	577
T2800B (40668)	364		

Note: Numbers in parenthesis (e.g. 40668) are former RCA type numbers.

When incorporating RCA Solid State Devices in equipment, it is recommended that the designer refer to "Operating Considerations for RCA Solid State Devices", Form No. 1CE-402, available on request from RCA Solid State Division, Box 3200, Somerville, N.J. 08876.

RCA
Solid State
Division

Thyristors/Rectifiers
Application Note
AN-6248

The ITR for Horizontal Deflection

W. E. Babcock

The introduction by RCA in 1968 of SCR's capable of perating at horizontal scanning rates made possible the evelopment of the first commercial horizontal-deflection ystem for color which was competitive in performance with eluxe systems using vacuum tubes. A new device, the ITR, he integrated thyristor and rectifier, has recently been eveloped for use in the system. The ITR offers the advantages f lower circuit cost and greater circuit flexibility. This Note describes the new device and its advantages, and disusses several variations for the deflection circuit in which t can be utilized.

Basic SCR Deflection Circuit

A simplified sketch of the SCR horizontal-deflection ystem is shown in Fig. 1. This system requires two bipolar witches—each switch being made up of a fast-turnoff SCR with a fast-recovery rectifier connected across it in reverse-olarity. In each case, the rectifier conducts the reverse urrent during the period required for the SCR to recover orward blocking capability[1]. As originally conceived, the ystem proved to have a number of advantages compared to revious solid-state deflection systems. After 5 years of use n production receivers these advantages still exist:

1. Peak voltages on the devices are low—below 500 volts on the trace switch and below 400 volts on the commutating switch.
2. Transient voltages due to arcing are relatively low—generally less than 100 volts above the steady-state repetitive value.
3. Devices used can be readily produced by standard factory processes—no new technology required.
4. Both system and devices proved to be easily adaptable to changing requirements—higher beam current, increased high voltage, wider deflection angles, torroidal yokes, etc.
5. Reliability of the system is excellent.

Development of the ITR

The circuit of Fig. 1 shows that, in both the trace and ommutating switches, the rectifier is connected directly across its associated SCR. A logical advance in device development was to explore the possibility of combining the SCR and the rectifier on a common silicon substrate. Fig. 2 shows how this is done.

When a separate SCR and rectifier are used in the deflection circuit, the SCR cathode is shorted to the rectifier anode and the SCR anode is shorted to the rectifier cathode by external connections. In the combined device, these elements are shorted together through the lead metallization on the surface of the pellet.

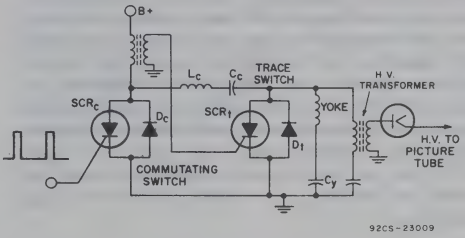


Fig. 1— Circuit showing rectifier connected directly across its associated SCR in both trace and commutating switches.

The combined device is really an SCR which conducts in the reverse as well as the forward direction, and might properly be termed a reverse-conducting SCR. However, it is also an SCR (thyristor) integrated (combined) in the same pellet with a rectifier, so it has been commonly called an ITR, which is an abbreviation for Integrated Thyristor and Rectifier. Use of such a device represents a savings in receiver assembly, since only two devices need be wired into the circuit instead of four. It also represents a potential savings in device cost, since the ultimate cost of two ITR's should not be appreciably different from the cost of two individual SCR's.

The combination of the SCR and rectifier on a common pellet as shown in Fig. 2 may seem straightforward, but the achievement of performance fully equivalent to two separate devices presents a real challenge to the device designer.

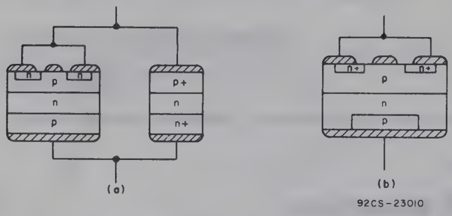


Fig. 2– (a) Separate SCR and rectifier, (b) combined device.

For example, consider the effect which can be produced by the transition in yoke current from the trace rectifier to the trace SCR, as shown in Fig. 3. Any delay in the initiation of the trace SCR current after the trace rectifier current decays to zero will cause the electron beam on the face of the picture tube to momentarily slow down. The result is a vertical white line at the center of the screen. When two separate devices are used, this problem can be overcome quite simply by tapping the rectifier section down about one turn (more negative) on the high-voltage transformer. Obviously, this cannot be done with the ITR, since the devices are directly connected together by the metallization pattern. The solution to this problem lies in adjusting the geometry of the device and controlling the processing to minimize the transient forward voltage drop at turn-on. In the more recent deflection circuits using the ITR, this problem is minimized further by increasing the peak pulse voltage on the trace switch somewhat thus making the turn-on voltage a smaller fraction of the total trace voltage. This technique had previously proven to be quite successful in European television systems using SCR's. These receivers operate at higher B-supply voltage and higher pulse voltage on the trace switch, yet the white line has not been a problem even though the rectifier has not been tapped down on the high-voltage transformer.

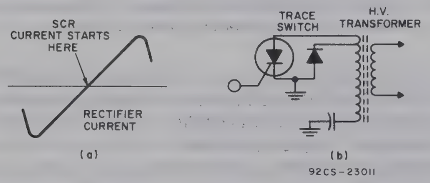


Fig. 3– (a) Yoke current, (b) compensation for rectifier/SCR current transition.

The turn-off capability of the ITR in the deflection circuit must be equivalent to that of the bipolar switch using separate devices. During the turn-off period of the SCR section, it is important that carriers from the rectifier section of the combined device **not** be injected into the SCR section, turning the SCR on again. This is especially true in circuits in which the rectifier section reverse-recovery current is very high. The ITR geometry has been designed to provide isolation between the SCR and rectifier sections, so that carrier injection from the rectifier section into the SCR section is minimized.

The cost-savings provided by using the ITR instead of separate devices is obvious. In addition, the ITR should provide better circuit reliability, greater circuit flexibility, and, in the very near future, lower device cost. These advantages are a result of lower leakage, higher voltage capability and adaptability to plastic packaging.

In a television deflection application, leakage, in itself, has very little effect on circuit performance unless it becomes comparable in magnitude to the normal on-state current. However, very high leakage, drastic increases in leakage with life or with increasing temperature, can be an indication of a degradation in the surface condition of the device, and can lead to eventual breakdown failure under high-voltage stress. Since the ITR has no reverse-blocking junction, and the rectifier unit has been put on the outer periphery of the pellet, the edge of the pellet presents a simple rectifier junction to the "outside world" rather than the pair of junctions of a conventional SCR. Consequently, the surface leakage path is that of a simple rectifier rather than the complex leakage path of an SCR. This leakage path in inherently one which presents a very high resistance to the flow of leakage current. In addition, elimination of the reverse-blocking junction makes it possible to design for higher inherent forward-blocking voltage, resulting in lower bulk leakage in the device.

The increased voltage capability of the ITR tends to make it somewhat easier to use the device over a wide range of supply voltages and deflection yoke inductances. The SCR deflection circuitry, as originally developed, operated from a supply voltage of about 150 volts and required a peak-voltage capability of about 450 volts on the devices. Extension of SCR deflection to higher B-supply voltage, such as the 270 volts commonly used in European receivers, wider deflection angles, torroidal yokes, supplying the other portions of the receiver from the deflection circuit, etc., all tend to increase the peak voltage applied to the deflection devices. The higher inherent voltage capability of the ITR makes it possible to meet the new requirements with essentially the same yield as previously obtained on the SCR's at the lower voltage.

One major device cost reduction which is planned for the ITR is to use a plastic package. Since the edge of the pellet contains only a simple rectifier junction, the passivation techniques normally used with plastic encapsulated SCR's are not required. A relatively large number of plastic encapsulated ITR's have already been made and show excellent characteristics. Reliability evaluations are in process and should be complete in time for commercial announcement of a plastic ITR in 1974.

Deflection Circuits Using ITR's

The ITR is directly applicable to circuitry previously developed to use separate SCR's and rectifiers. Adequate power-handling capability is available for any known color television deflection application. Fig. 4 shows the basic deflection circuitry which has been used with SCR's for several years. The B-plus supply to this circuit is unregulated, but

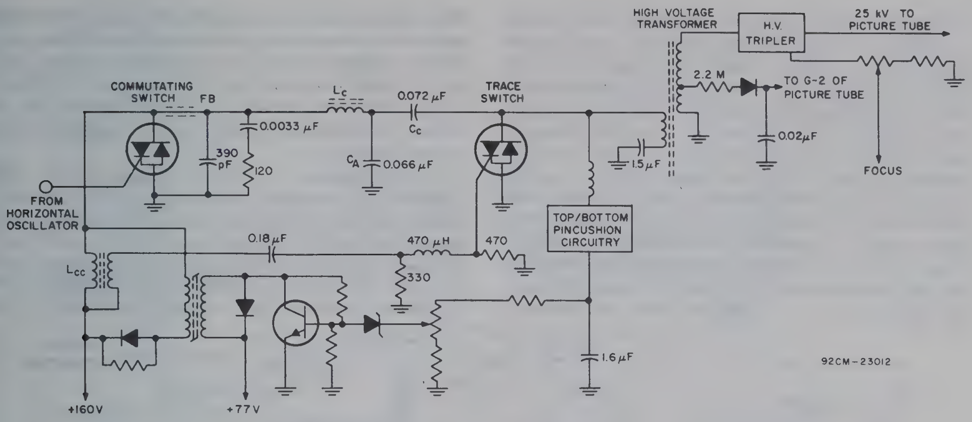

HIGH VOLTAGE TRANSFORMER
H.V. TRIPLER
25 kV TO PICTURE TUBE
2.2 M
TO G-2 OF PICTURE TUBE
0.02μF
FOCUS
COMMUTATING SWITCH
FB
Lc
0.072 μF
Cc
TRACE SWITCH
0.0033 μF
390 pF
120
CA
0.066 μF
1.5μF
FROM HORIZONTAL OSCILLATOR
TOP/BOTTOM PINCUSHION CIRCUITRY
0.18μF
470 μH
470
Lcc
330
1.6μF
92CM-23012
+160V
+77V

Fig. 4– ITR's in a deflection circuit originally developed to use separate SCR's and rectifiers.

scan is regulated against changes in line voltage by controlling he amount of energy delivered to the system. The trace circuit is supplied by energy which is stored primarily in the ommutating and auxiliary capacitors, C_C and C_A. These apacitors are charged from the B-supply through the input eactor L_{CC} during the trace interval. The voltage on the oke return capacitor, which is a function of scan, is compared with a reference zener and used to control the collector current of a regulator transistor. The collector current of this egulator transistor flows through the control winding of the aturable reactor which is in shunt with L_{CC}. This action ends to vary the effective inductance of L_{CC}, and thus the energy stored in C_C and C_A, in such a way that scan is maintained constant with variations in both line voltage and beam current. Power losses are extremely low since the net reactance in the system is controlled to provide regulation, rather than by controlling applied voltage with dissipative elements.

Another regulator circuit which uses semiconductor devices instead of a saturable reactor and which is applicable to either ITR's or SCR's is shown in Fig.5.[2] In this circuit, the voltage from an auxiliary winding on the input reactor is rectified by an SCR (SCR_R) and added to the voltage obtained from the main power supply rectifier, thus "boosting" the B-supply to

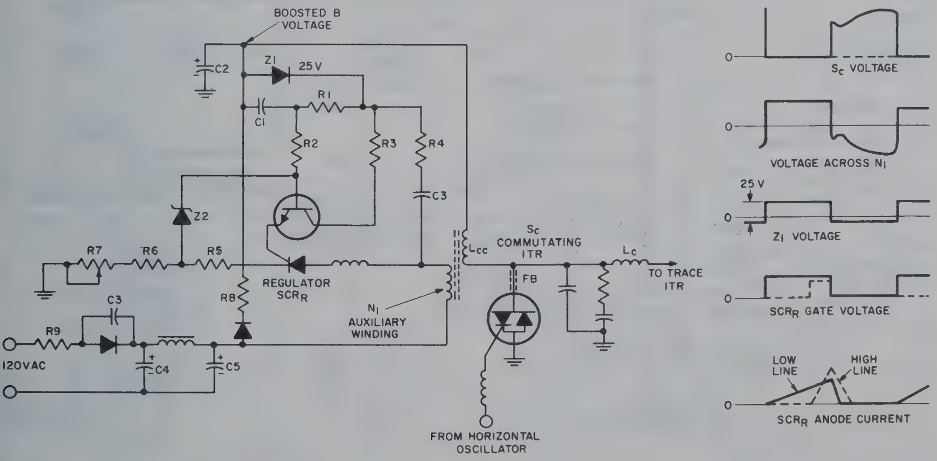

BOOSTED B VOLTAGE
C2
Z1
25V
R1
C1
R2
R3
R4
C3
Z2
R7
R6
R5
R8
REGULATOR SCRR
N1 AUXILIARY WINDING
Lcc
Sc COMMUTATING ITR
FB
Lc
TO TRACE ITR
C3
R9
120VAC
C4
C5
FROM HORIZONTAL OSCILLATOR
0
Sc VOLTAGE
VOLTAGE ACROSS N1
25 V
Z1 VOLTAGE
SCRR GATE VOLTAGE
LOW LINE
HIGH LINE
SCRR ANODE CURRENT

Fig. 5– Boost regulator circuit which uses semiconductor devices instead of a saturable reactor, and which is applicable to either ITR's or SCR's.

92CM-23013

the deflection system to a higher value. The amount of boost is controlled by regulating the conduction period of the regulator SCR. This SCR is gated on by a positive sawtooth which is formed from the voltage on the auxiliary windings by means of a zener and an integrating network (Z_1, R_1, C_1) and then amplified by the regulator transistor. The composite boosted voltage is compared against a reference zener (Z_2), regulating the base drive to the regulator transistor and the resulting gate drive to the regulator SCR. As a result of this action, the boost voltage which is added to the main B-supply voltage varies from a maximum at low line to very nearly zero at high line. Power losses with this system are even lower than with the saturable reactor system previously described, since the copper losses of the saturable reactor are eliminated.

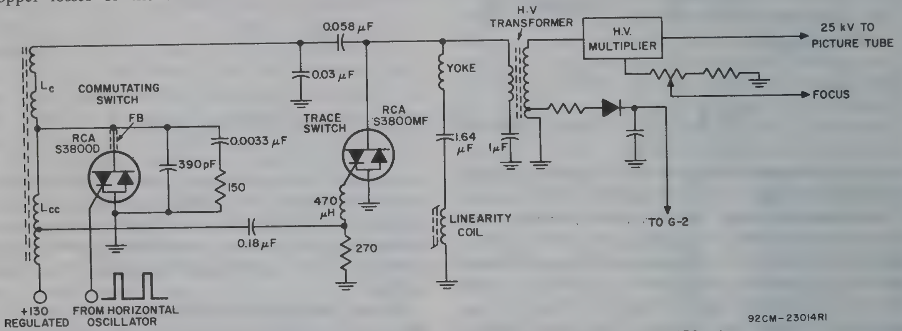

0.058 μF
H.V TRANSFORMER
H.V. MULTIPLIER
25 kV TO PICTURE TUBE
FOCUS
0.03 μF
YOKE
Lc
COMMUTATING SWITCH
FB
RCA S3800D
0.0033 μF
390 pF
150
TRACE SWITCH
RCA S3800MF
1.64 μF
1μF
470 μH
Lcc
0.18 μF
270
LINEARITY COIL
TO G-2
+130 REGULATED
FROM HORIZONTAL OSCILLATOR
92CM-23014RI

Fig. 6– System designed to operate from a regulated supply of approximately 130 volts.

The saturable reactor type of regulator circuit and the boost regulator are particularly suited to deflection systems using SCR's or ITR's, but it would be quite difficult to adapt either regulator circuit for use with any other type of deflection system. The reverse is not true, however. Operation from conventional regulated supplies, such as a series transistor regulator, a 60-Hz phase-controlled SCR regulator, or a ferroresonant transformer, presents no particular problem. Fig. 6 shows a system designed to operate from a regulated supply of about 130 volts.

If the equipment manufacturer feels his market will tolerate changes in picture width with changing line voltage, regulation of the B-supply voltage can be eliminated completely. Such a system could be commercially acceptable for a black and white receiver or for a low-cost color receiver. Fig. 7 shows the schematic of a deflection circuit for a black and white receiver operating from a simple half-wave line rectifier with no regulation. In addition, all other voltages for the receiver (except the horizontal oscillator), including the picture-tube heater, are derived from the deflection system. Fig. 8

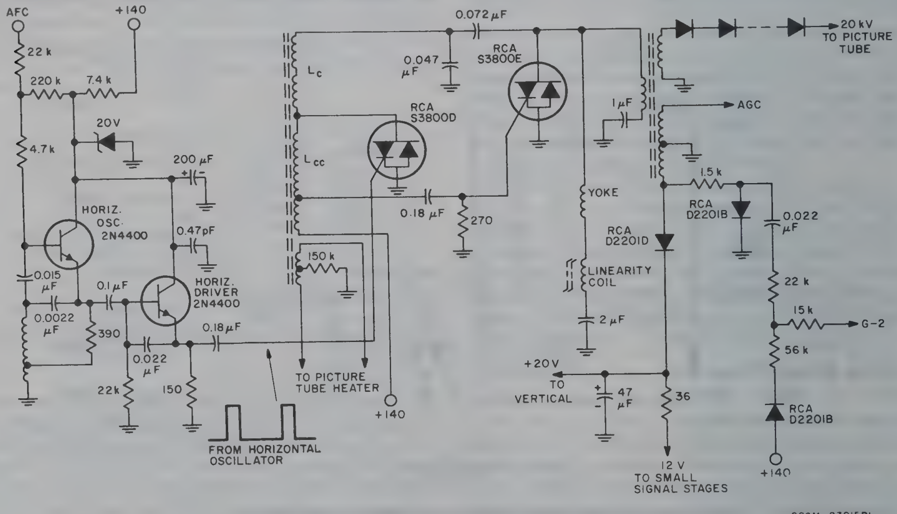

AFC
+140
22 k
220 k
7.4 k
20V
4.7 k
200 μF
HORIZ. OSC. 2N4400
0.47 pF
0.015 μF
0.1 μF
HORIZ. DRIVER 2N4400
0.0022 μF
390
0.18 μF
0.022 μF
22k
150
TO PICTURE TUBE HEATER
+140
FROM HORIZONTAL OSCILLATOR
0.072 μF
0.047 μF
Lc
RCA S3800E
RCA S3800D
Lcc
0.18 μF
270
150 k
20 kV TO PICTURE TUBE
1 μF
AGC
1.5 k
RCA D2201B
0.022 μF
YOKE
RCA D2201D
LINEARITY COIL
2 μF
22 k
15 k
G-2
56 k
+20 V TO VERTICAL
47 μF
36
RCA D2201B
12 V TO SMALL SIGNAL STAGES
+140
92CM-23015RI

Fig. 7– Schematic diagram of a deflection circuit for a black and white receiver operating from a simple half-wave line rectifier with no regulation.

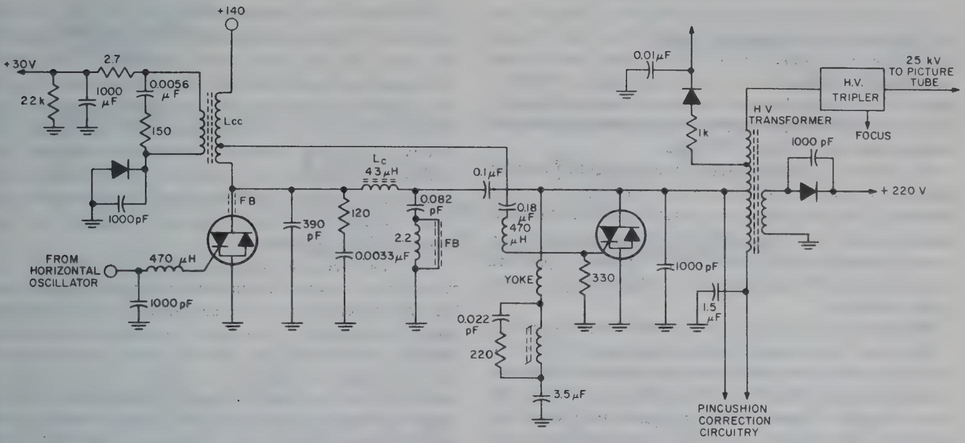
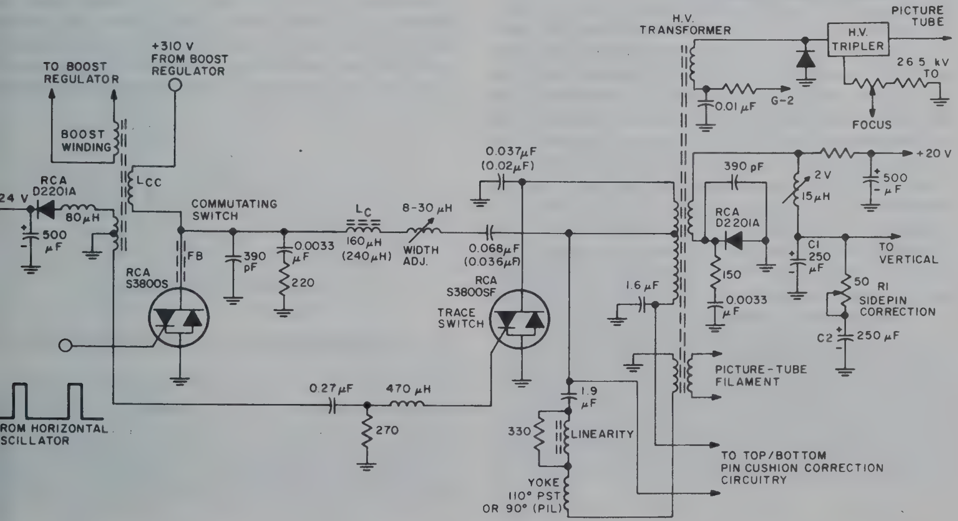

+140
+30V
2.7
22k
1000 μF
0.0056 μF
150
Lcc
1000pF
FB
FROM HORIZONTAL OSCILLATOR
470 μH
1000pF
390 pF
120
Lc 43μH
0.0033μF
0.082 pF
2.2
FB
0.1μF
0.18 μF
470 μH
YOKE
0.022 pF
220
3.5μF
330
1000 pF
1.5 μF
0.01μF
1k
H V TRANSFORMER
H.V. TRIPLER
25 kV TO PICTURE TUBE
FOCUS
1000 pF
+ 220 V
PINCUSHION CORRECTION CIRCUITRY

Fig. 8— Horizontal-deflection system of a commercial low-cost color receiver operating from rectified line voltage with no B-supply regulation.

92CM-23016

hows the horizontal deflection system of a commercial low-cost color receiver operating from rectified line voltage with no B-supply regulation. This receiver also derives the other equired operating voltages from the deflection system.

Since the announcement of the 90° Precision-in-Line color picture tube with its integral torroidal yoke, the availability of 110° color picture tubes in Europe with the PST torroidal yoke, and the sampling of 110° color picture tubes in the U.S., some work has been done on the development of a "universal" ircuit for the two tubes. A simplified schematic of such a circuit is shown in Fig. 9. In this schematic, the component values for the P.I.L. tube which differ from those for the 110° tube are shown in brackets. This particular circuit has been designed for use with the relatively high B-supply voltage which would be available in a European receiver. Some adjustment of the component values would be required for operation in a U.S. receiver which might have a B-supply of 250 volts. Incidentally, the high-voltage capability of the ITR is an advantage in this circuit, since both trace and commutating switches must be rated above 700 volts.


TO BOOST REGULATOR
+310 V FROM BOOST REGULATOR
BOOST WINDING
LCC
RCA D2201A
24 V
80μH
500 μF
COMMUTATING SWITCH
FB
RCA S3800S
390 pF
0.0033 μF
220
Lc 160μH (240μH)
8-30 μH
WIDTH ADJ.
0.037μF (0.02μF)
0.068μF (0.036μF)
RCA S3800SF
TRACE SWITCH
ROM HORIZONTAL SCILLATOR
0.27μF
470 μH
270
1.9 μF
330
LINEARITY
YOKE 110° PST OR 90° (PIL)
1.6 μF
H.V. TRANSFORMER
0.01 μF
G-2
H.V. TRIPLER
PICTURE TUBE
26 5 kV TO
FOCUS
390 pF
RCA D2201A
150
0.0033 μF
2V
15μH
+20 V
500 μF
C1 250 μF
TO VERTICAL
50 R1 SIDEPIN CORRECTION
C2 250 μF
PICTURE-TUBE FILAMENT
TO TOP/BOTTOM PIN CUSHION CORRECTION CIRCUITRY

92CM-22998R1

Fig. 9— Simplified schematic diagram of a "universal" circuit adaptable to 90° and 110° picture tubes.

Fortunately the voltage across the 90° P.I.L. yoke and the 110° PST yoke for full scan is the same. Therefore, the same high-voltage transformer can be used for both the 90° and 110° systems. In order to meet the voltage rating on the P.I.L. yoke, the low end of the yoke is returned to ground through a 5-turn bucking winding on the high-voltage transformer. This winding is not used with the 110° yoke.

For a deluxe receiver, provision for adjustment of width is desirable in order to compensate for variations in circuit tolerances. This adjustment is provided by using a small variable inductor in series with the commutating inductor. A width adjustment of approximately ±4 percent is provided by this control with negligible effect on high voltage or high-voltage regulation.

When the vertical dc supply voltage is obtained by rectifying a pulse from the horizontal system as shown in Fig. 9, it is possible to obtain side pincushion correction with a minimum of added circuit components. The filter capacitor for the vertical supply is made somewhat smaller than would be required to provide pure dc at the output of the vertical supply rectifier. Current through the vertical supply rectifier and voltage output of the vertical supply are shown in Fig. 10.

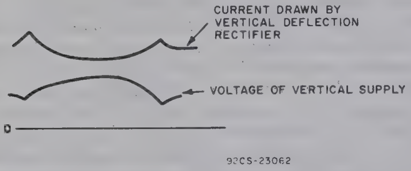


Fig. 10– Current through the vertical supply rectifier and voltage output of the vertical supply.

It can be seen that current drawn by the vertical circuit is a maximum at the beginning and end of scan and a minimum at the center of scan. This current represents a load on the horizontal scan circuit, reducing scan at the top and bottom of the picture, thus providing side pincushion correction. The series inductor L_V, in combination with C_1, C_2, and R_1 modify the loading to provide symmetrical correction. This method of side pincushion correction is applicable to any horizontal deflection circuit using either ITR's or SCR's if the voltage supply for vertical deflection is derived from the horizontal deflection system.

RCA has been in volume production of the ITR for approximately a year. No unusual production problems have been encountered and circuit performance in the deflection application appears to be excellent. It is anticipated that, in the relatively near future, ITR's will be used in most horizontal deflection systems which now use SCR's. The opportunity they offer for cost savings (especially when plastic devices become available), and their easy adaptability to wider deflection angles, varying yoke inductances, wide range of B-supply voltages and the like, should result in their being designed into many deflection systems yet to be developed.

References

1. For a complete explanation of the SCR deflection system, see "An SCR Horizontal-Sawtooth-Current and High-Voltage Generator for Magnetically Deflected Picture Tubes", W. F. Dietz, IEEE Transactions on Broadcast and TV Receivers, or RCA Application Note AN-3780.
2. "A Thyristor Regulator Circuit for SCR Deflection," W. Dietz, IEEE Transactions on Broadcast and TV Receivers, Feb. 1973, Vol. 8TR 19, No.1; or RCA Technical Reprint No. ST-6136.

RCA
Solid State Division

Thyristors and Rectifiers
Application Note
AN-6286

Latching, Gate-Trigger Circuits Using Thyristors for Machine-Control Applications

by M. Kalfus

Electromechanical latching circuits used in mechanical proessing equipment require large numbers of electromechanical evices; these devices generate line transients, periodically alfunction (mechanically), and ultimately fail as a result of ontact erosion. In addition, they are sometimes noisy, and add the already noise-polluted environment. This Note describes a riety of approaches to the development of a solid-state, latchg gate drive for the control of ac loads; the solid-state device sed is the thyristor. The solid-state circuits described below ave fewer undesirable characteristics than the electroechanical devices and are smaller and lighter.

LATCHING GATE–TRIGGER CIRCUITS

In many applications, particularly industrial machine conols, a latching relay is often used to permit a system or substem to be activated by a momentary pulse from a control ocessor or hand actuator. A basic latching circuit using an ectromechanical relay is shown in Fig. 1. S1 is momentarily osed to pull contacts A and B of relay K closed. Once contact A closed, S1 may be opened. Relay K and the load will remain tivated until S2 is momentarily opened either manually or by a achine mechanism which has completed its cycle of operation.

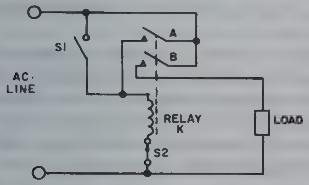


Fig. 1—Basic latching circuit using electromechanical relay.

A solid-state approach to this type of circuit, Fig. 2, offers duced power consumption and a more compatible interface ith process-control computers. In this simplified circuit, an ternal dc supply provides dc gate drive to power the COS/MOS p-flop and collector current to drive the triac gate. Sufficient te current must be available through R to meet the I+ and III+ gate requirements of the triac; an RsCs snubber network should be used when inductive loads are being controlled.

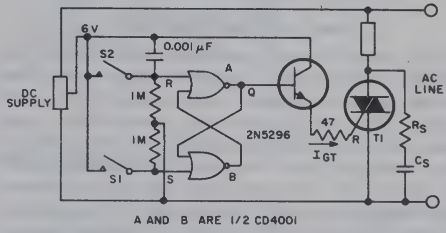


Fig. 2—Two dual-input NOR gates connected to form set-reset flip-flop.

In Fig. 2, two dual-input NOR gates, A and B, are connected to form a set-reset flip-flop which changes the state of the Q output when the voltage on either the S or the R input terminal is at a high level; the effective input will be that one last used. Power drain for the flip-flop circuit is negligible compared with that of the transistor driver stage supplying current to the triac gate. Power-supply requirements are, therefore, determined by the triac gating characteristics. The power requirements of the driver transistor are also a function of the triac gate characteristics. Since this circuit gates the triac in the dc mode, latching difficulties resulting from highly inductive load conditions or loads with very low power consumption can be eliminated. Except for the first half cycle of conduction, the triac will be in the on state continuously, and only an absolute minimum of radio-frequency interference will be generated on the subsequent half cycles. Of course, turn-off always occurs as the load current reduces to zero after gate drive has been removed.

Fig. 3 shows the waveforms of voltage and current in the triac circuit as a function of the control-circuit inputs for a resistive load. The low-level spike (2 to 4 volts) observed across the triac at the beginning of each half cycle occurs because of the operating characteristics of thyristors. A minimum voltage of 2 to 4 volts is generally necessary across a triac to initiate the regeneration process of the four-layer device, even in the presence of a dc gate bias.

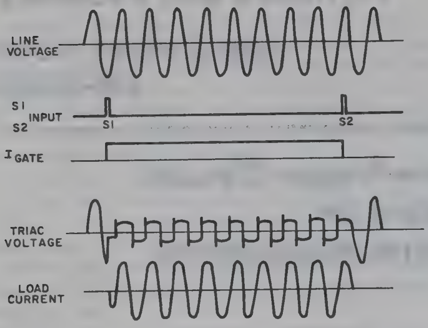


Fig. 3–Triac-circuit current and voltage waveforms as a function of control-circuit inputs for resistive load.

ZERO–VOLTAGE SWITCHES

RCA, integrated-circuit, zero-voltage switches (ZVS) are particularly well suited for use as thyristor trigger circuits. These switches trigger the thysistor at zero-voltage points in the supply-voltage cycle. Consequently, transient-load current surges and radio-frequency interference are substantially reduced. In addition, use of the zero-voltage switch also reduces the rate of change of on-state current (di/dt) in the thyristor being triggered, an important consideration in the operation of thyristors. These zero-voltage switches can be adapted for use in a variety of control functions by use of an internal differential comparator to detect the difference between two externally developed voltages. In addition, the availability of numerous terminal connections to internal circuit points greatly increases circuit flexibility and further expands the types of ac power-control applications to which these integrated circuits may be adapted. The excellent versatility of the zero-voltage switches makes them particularly useful in circuits designed to provide transient-free temperature control in self-cleaning ovens, to control gun-muzzle temperature in low-temperature environments, to provide sequential switching of heating elements in warm-air furnaces, to switch traffic-signal lights at street intersections, and to provide other diverse ac power-control functions.

Functional Description

RCA zero-voltage switches are multistage circuits that employ a diode limiter, a zero-crossing (threshold) detector, an on-off sensing amplifier (differential comparator), and a Darlington output driver (thyristor gating circuit) to provide the basic switching action. The dc operating voltages for these stages are provided by an internal power supply that has sufficient current capability to drive external circuit elements, such as transistors and other integrated circuits. An important feature of the zero-voltage switches is that the output trigger pulses can be applied directly to the gate of a triac or a silicon controlled rectifier (SCR). The CA3058 and CA3059 zero-voltage switches also feature an interlock (protection) circuit that inhibits the application of these output trigger pulses to the thyristor in the event that the external sensor is inadvertently opened or shorted. An external inhibit connection (terminal No. 1) is also available, so that an external signal can be used to inhibit the output drive. This feature is not included in the CA3079; otherwise, the three integrated-circuit zero-voltage switches, CA3058, CA3059, and CA3079, are electrically identical.

Overall Circuit Operation

Fig. 4 shows the interrelation of the functions in a zero-voltage switch, the external sensor, the thyristor being triggered, and the load elements, in an on/off type of ac power-control system. Fig. 5 shows the detailed circuit diagram for the integrated-circuit zero-voltage switches. Figs. 4 and 5 are representative of all three RCA zero-voltage switches, the CA3058, CA3059, and CA3079; the shaded areas in the figures indicate the circuitry that is not included in the CA3079.

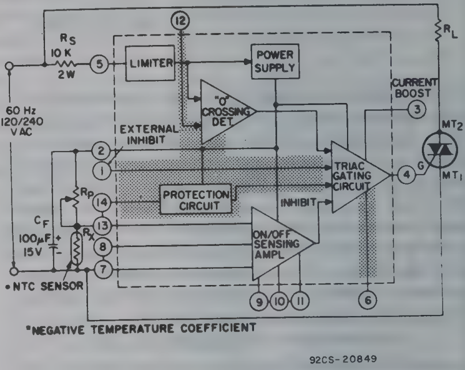


Fig. 4–Functional block diagram of CA3059 IC zero-voltage switch.

As shown in Fig. 4, each of the three zero-voltage switches incorporates four primary functions:

1. Limiter-Power Supply – permits operation directly from an ac line.
2. Differential On/Off Sensing Amplifier – tests the condition of external sensors or command signals. Hysteresis or proportional-control may be implemented easily in this section.
3. Zero-Crossing Detector – synchronizes the output pulses of the circuit at the time when the ac cycle is at a zero-voltage point and thereby eliminates radio-frequency interference when the ZVS is used with resistive loads.
4. Triac Gating Circuit – provides high-current pulses to the gate of the power-controlling thyristor.

In addition, the CA3058 and CA3059 are provided with the following important auxiliary features:

1. A built-in protection circuit that may beactuated to remove drive from the triac if the sensor becomes open o short-circuited.
2. An internal diode gate connected to terminal 1 that can be used to inhibit thyristor firing.

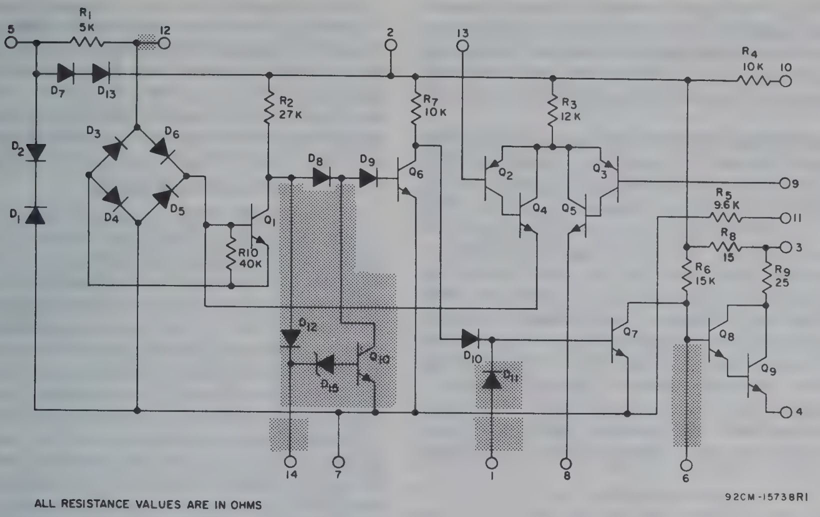


Fig. 5—Schematic diagram of CA3059 zero-voltage switch.

3. A means of attaining dc comparator operation by overriding the action of the zero-crossing detector. This override is accomplished by connecting terminal 12 to terminal 7. Gate current to the thyristor is continuous when terminal 13 is positive with respect to terminal 9, but is time-deviation limited and a function of the filter capacitor and the terminating impedance at terminal 4.

The limiter stage of the zero-voltage switch clips the incoming ac line voltage to approximately ±8 volts. This signal is then applied to the zero-voltage crossing detector, which generates an output pulse each time the line voltage passes through zero. The limiter output is also applied to a rectifying diode and an external capacitor, C_F, that compose the dc power supply. The power supply provides approximately 6 volts, as the V_{CC} supply, to the other stages of the zero-voltage switch. The on/off sensing amplifier is basically a differential comparator. The thyristor gating circuit is enabled when the line voltage is approximately zero volts, the sensing-amplifier output is high, the external voltage to terminal 1 is a logical zero, and, for the CA3058 and CA3059, the output of the fail-safe circuit is high. Under these conditions, the thyristor (triac or SCR) is triggered when the line voltage is essentially zero volts.

THYRISTOR TRIGGERING CIRCUITS

Diodes D1 and D2 in Fig. 5 form a symmetrical clamp that imits the voltages on the chip to ±8 volts; diodes D7 and D13 orm a half-wave rectifier that develops a positive voltage on the xternal storage capacitor, C_F.

The output pulses used to trigger the power-switching thyristor are actually developed by the zero-crossing detector and the thyristor gating circuit. The zero-crossing detector consists of diodes D3 through D6, transistor Q1, and the associated resistors shown in Fig. 5. Transistors Q1 and Q6 through Q9 and the associated resistors compose the thyristor gating circuit and output driver. These circuits generate the output pulses when an ac input is at a zero-voltage point, so that rfi is virtually eliminated when the zero-voltage switch and thyristor are used with resistive loads.

The operation of the zero-crossing detector and thyristor gating circuit can be explained more easily if the on state (i.e., the operating state in which current is being delivered to the thyristor gate through terminal 4) is considered as the operating condition of the gating circuit. Other circuit elements in the zero-voltage switch inhibit the gating circuit unless certain conditions are met, as explained below.

In the on state of the thyristor gating circuit, transistors Q8 and Q9 are conducting, transistor Q7 is off, and transistor Q6 is on. Any action that turns on transistor Q7 removes the drive from transistor Q8 and thereby removes gate drive from the thyristor. Transistor Q7 may be turned on directly by application of a minimum of ±1.2 volts at 10 microamperes to the external-inhibit input terminal 1. (If a voltage of more than 1.5 volts is available, an external resistance must be added in series with terminal 1 to limit the current to 1 milliampere.) Diode D10 isolates the base of transistor Q7 from other signals when an external inhibit signal is applied, so that this signal is the highest priority command for normal operation. (Although grounding of terminal 6 creates a higher priority inhibit function, this level is not compatible with normal DTL or TTL logic levels.)

Transistor Q7 may also be activated by turning off transistor Q6 to allow current flow from the power supply through resistor R7 and diode D10 into the base of Q7. Transistor Q6 is normally maintained in conduction by current that flows into its base through resistor R2 and diodes D8 and D9 when transistor Q1 is off.

Transistor Q1 is a portion of the zero-crossing detector. When the voltage at terminal 5 is greater than +3 volts, Q1 can be turned on by a current flowing through resistor R1, diode D6, the base-to-emitter junction of transistor Q1, and diode D4 to terminal 7. This action inhibits the delivery of a gate-drive output signal at terminal 4. For negative voltages at terminal 5 that have magnitudes greater than 3 volts, the current flows through diode D5, the emitter-to-base junction of transistor Q1, diode D3, and resistor R1, and again turns on transistor Q1. Transistor Q1 is off only when the voltage at terminal 5 is less than the threshold voltage of approximately ±2 volts. When the integrated-circuit zero-voltage switch is connected as shown in Fig. 4, therefore, the output is a narrow pulse which is approximately centered about the zero-voltage time in the cycle, as shown in Fig. 6. In some applications, however, particularly those that use either slightly inductive or low-power loads, the thyristor load current does not reach the latching-current value* by the end of this pulse. An external capacitor, C_X, connected between terminal 5 and 7, as shown in Fig. 7, can be used to delay the pulse to accommodate such loads.

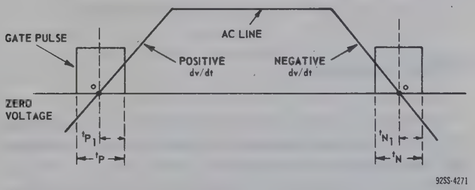


Fig. 6—Waveform showing output-pulse duration of zero-voltage switch.

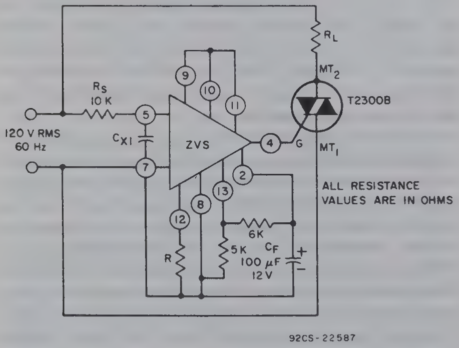


Fig. 7—Use of capacitor between terminals 5 and 7 to delay output pulse of zero-voltage switch.

Continuous gate current can be obtained if terminal 12 is connected to terminal 7 to disable the zero-crossing detector. This mode of operation is useful when comparator operation is desired or when inductive loads must be switched. (If the capacitance in the load circuit is low, most rfi is eliminated.) Care must be taken to avoid overloading of the internal power supply in this mode since the filter capacitor and gate impedance at terminal 4 affect the regulation of the internal power supply.

Effect of Thyristor Load Characteristics

The zero-voltage switch is designed primarily to gate a thyristor that switches a resistive load. Because the output pulse supplied by the switch is of short duration, the latching current of the triac becomes a significant factor in determining whether other types of loads can be switched. (The latching-current value determines whether the triac will remain in conduction after the gate pulse is removed.) Provisions are included in the zero-voltage switch to accommodate inductive loads and low-power loads. For example, for slightly inductive loads, it is possible to retard the output pulse with respect to the zero-voltage crossing by insertion of capacitor C_X from terminal 5 to terminal 7. The insertion of capacitor C_X permits switching of triac loads that have a slight inductive component and a power dissipation greater than approximately 200 watts (for operation from an ac line voltage of 120 volts rms). However, for loads less than 200 watts (for example, 70 watts), it is recommended that the user employ the T2300B† sensitive-gate triac with the zero-voltage switch because of the low latching-current requirement of this triac.

For loads, such as a solenoid valve, that have a low power factor, the user may operate the zero-voltage switch in the dc mode. In this mode, terminal 12 is connected to terminal 7, and the zero-crossing detector is inhibited. Whether a "high" or "low" voltage is produced at terminal 4 is then dependent only upon the state of the differential comparator within the integrated-circuit zero-voltage switch, and not upon the zero crossing of the incoming line voltage. Of course, in this mode of operation, the zero-voltage switch no longer operates as a zero-voltage switch. However, for many applications that involve the switching of low-current inductive loads, the amount of rfi generated can be tolerated.

SWITCHING OF INDUCTIVE LOADS

Gate drive must be applied to a thyristor in full-cycle operation soon after the current through the device reverses. When resistive loads are used, this reversal occurs as the line voltage reverses. With loads of other power factors, however, the current reversal occurs out of phase with the line voltage.

There are several methods for switching an inductive load at the proper time. If the power factor of the load is high (i.e., if the load is only slightly inductive), the pulse may be delayed by addition of a suitable capacitor between terminals 5 and 7, as described previously. For highly inductive loads, however, this method is not suitable, and different techniques must be used.

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*The latching current is the minimum current required to sustain conduction immediately after the thyristor is switched from the off to the on state and the gate signal is removed.

†Formerly RCA-40526

If gate current is continuous, the triac will automatically everse current. This mode of operation is established by conection of terminals 7 and 12. The zero-crossing detector is hen disabled, so that gate-current is supplied to the triac vhenever called for by the sensing amplifier. Although the fi-eliminating function of the zero-voltage switch is inhibited vhen the zero-crossing detector is disabled, the problem is ninimal if the load is highly inductive because the current in he load cannot change abruptly.

Circuits that use a sensitive-gate triac to shift the firing point f the power triac by approximately 90 degrees have been deigned. If the primary load is inductive, this phase shift orresponds to firing at zero current in the load. However, hanges in the power factor of the load or tolerances of comonents will cause errors in this firing time.

The circuit shown in Fig. 8 uses a CA3018 integrated-circuit ansistor array to detect the absence of load current by sensing e voltage across the triac. The internal zero-crossing detector is isabled by connection of terminal 12 to terminal 7, and control f the output is made through the external inhibit input, erminal 1. The circuit permits an output only when the voltage t point A exceeds two V_{BE} drops, or 1.3 volts. When point A is ositive, transistors Q3 and Q4 conduct and reduce the voltage t terminal 1 below the inhibit state. When A is negative, transtors Q1 and Q2 conduct. When the voltage at point A is less han ±1.3 volts, neither of the transistor pairs conduct; erminal 1 is then pulled positive by the current in resistor R3, nd the output is inhibited.

The circuit shown in Fig. 8 forms a pulse of gate current, and can supply the high peak drive needed to power triacs, with a low average current drain on the internal supply. The gate pulse will always last just long enough to latch the thyristor, so that there is no problem with delaying the pulse to an optimum time. As in other circuits of this type, rfi results at initial turn-on if the load is not suitably inductive because the zero-crossing detector is disabled and initial turn-on occurs at random. The gate pulse is generated because the voltage at point A is less than 1.3 volts. When the thyristor is on, therefore, the output of the zero-voltage switch is inhibited, as described above. Resistor divider R1 and R2 should be selected to assure this condition. When the triac is on, the voltage at point A is approximately one-third of the instantaneous on-state voltage (V_T) of the thyristor. For most RCA thyristors, V_T (max) is less than 2 volts, and the divider shown is a conservative one. When the load current passes through zero, the triac commutates off. Because the circuit is still being driven by the line voltage, the current in the load attempts to reverse, and voltage increases rapidly across the "turned-off" triac. When this voltage exceeds 4 volts, one portion of the CA3018 conducts and removes the inhibit signal to permit application of gate drive. When the triac is turned on, the voltage across it drops, and the gate pulse ends. If the latching current has not been attained, another gate pulse forms, but with no discontinuity in the load current.

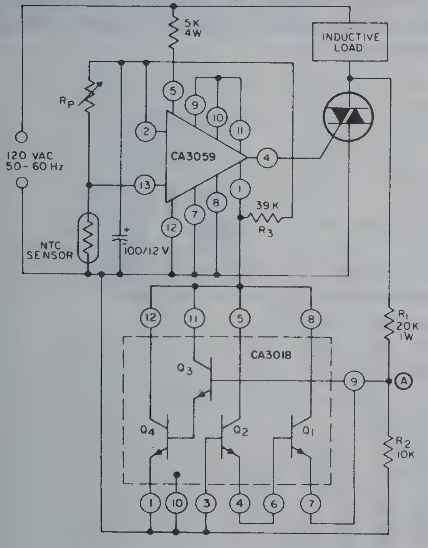


Fig. 8—Use of CA3058 or CA3059 together with CA3086 for switching inductive loads.

LATCHING CIRCUITS FOR RESISTIVE LOADS

When a resistive load, such as in an indicator lamp or heater element, is to be latched on, and the elimination of turn-on transients must be minimized, the circuit of Fig. 9 provides zero-voltage switching at the onset of turn on and at each half-cycle thereafter until switched off. In addition, this circuit provides dc power to the COS/MOS logic directly from the internal supply of the zero-voltage switch. The unused portion of the CD4001 can be applied to the other functions or to the same function if multiplicity of operation is required.

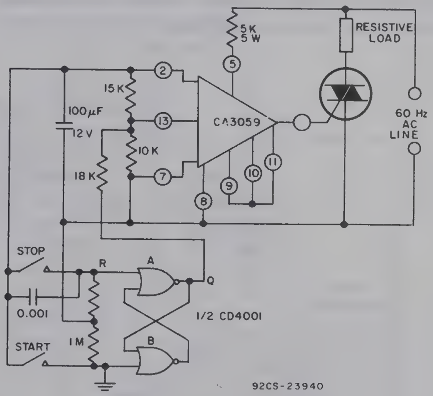


Fig. 9—Circuit that provides zero-voltage switching at the onset of turn-on and at each half cycle thereafter.

In the circuits of Figs. 2 and 9, the flip-flop logic function is implemented with low-power COS/MOS gates. However, in Fig. 9, the output, Q, controls the level of voltage at the input of a voltage comparator in the ZVS, terminal 13. Gate pulses generated at each zero-voltage crossing are generated from the ZVS at terminal 4 and drive the triac in the I+ and III+ gate modes. In Fig. 9 the triac is gated on at the beginning of each half cycle of ac line voltage, including the first half cycle, and rfi is virtually eliminated. However, because the gate pulses generated are very narrow (approximately 100 microseconds wide) at a time when line voltage is near zero (approximately 2.4 volts), this circuit is not recommended for use with highly inductive or low-power loads which prevent the minimum triac-latching current from flowing through the load circuit prior to the end of the gate pulse. The circuit of Fig. 10, a latching type circuit for electromechanical loads that uses the same basic logic as the circuit of Fig. 9, is suggested for the control of inductive loads by a triac.

LATCHING CIRCUITS FOR INDUCTIVE LOADS

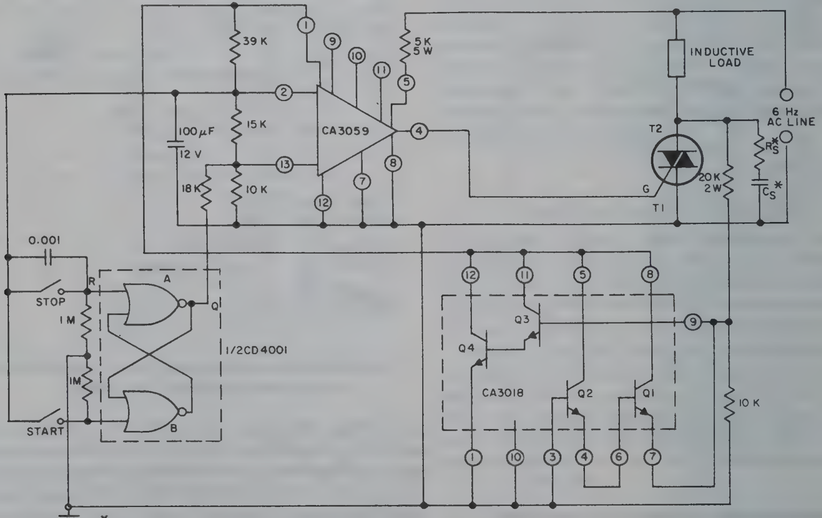
Fig. 10, a modification of the zero-voltage switch using a CA3018 transistor array, effectively converts the CA3059 into a zero load-current switch and provides a gate pulse long enough to assure that latching current is achieved. In this mode of operation the initial turn on can occur at random; however, as a result of the inductive nature of the load, rfi is usually minimal.

In Fig. 10, the CA3018 transistor array is used to sense the on state of the triac by monitoring the T1 to T2 voltage. Once the triac has latched on, the T1 to T2 voltage will be no greater than about 2.0 volts for any RCA triac operating within its ratings. The CA3018 interfaces with the ZVS switch at terminal 1. Terminal 12 is tied to terminal 7 to disable the zero-voltage crossing sensor. In this configuration, a gate output pulse at terminal 4 occurs when the following two conditions occur simultaneously; flip-flop output, Q, high, and triac T2 voltage greater than approximately 4 volts. As in the preceding circuits, dc supply voltage is available directly from the internal regulated supply of the ZVS.

An alternate logic function in some machine processes requires activation of the load after the start switch has been closed and opened; Fig. 11 is a typical electromechanical circuit which accomplishes this function. When switch S is moved to the B position, relay K is activated and latched on through the KB contacts. Load current is blocked by the open contact A at switch S; the contact remains open until switch S is released. Load current flows after switch S is released until the latched relay is de-energized by interrupting the current in the relay coil by opening switch R momentarily.

LATCHING CIRCUITS WITH HOLD-OFF FUNCTION

Fig. 12 shows a solid-state circuit whose function is identical with the circuit of Fig.11. In Fig.12, the ZVS is used as in Fig.9; Fig. 2 or Fig. 10 may be modified similarly, as the only change required involves the COS/MOS logic circuitry. No additional components are necessary to accomplish this logic function. In Fig. 12, a third dual-input NOR gate (unused in the circuits previously described) holds the $\bar{Q}$ output of the flip-flop off as long as the set or start switch, S, remains closed because the A input to gate III is held high. The closure of S has also changed the state of $\bar{Q}$ to a low level. When S is released or opened, the A and B inputs of gate III are both low, and the output, C, goes high and enables the ZVS to generate gate pulses to the triac. Capacitor C1 serves to integrate the set- or start-voltage step, thereby allowing time for switch contact bounce to subside; otherwise, transient pulses may appear at output C during closure of switch S.



*FOR SELECTION OF R_S AND C_S SEE RCA APPLICATION NOTE AN-4745

Fig. 10—A latching-type circuit for electromechanical loads.

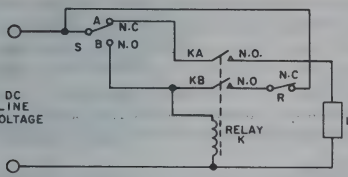

A
N.C
S
B
N.O
KA
N.O.
KB
N.O
N.C
R
DC
LINE
VOLTAGE
RELAY
K
LOAD
92CS-23935

Fig. 11—Electromechanical circuit that activates the load after the start switch has been closed and opened.

The circuit in Fig. 10 may be unusable in some applications equiring very low turn-on transients. Turn-on in this circuit can ccur anywhere within the first positive or negative half cycle nd can cause a significant rate of change of current in the load, articularly if the load is resistive in nature. Once latch-up of the rigger circuit is complete, each half-cycle trigger will occur vhen approximately ±4 volts appear across the main terminals f the thyristor.

ELAYED LATCHING WITH ZERO-VOLTAGE SWITCHING

Fig. 13 is a latching circuit which switches the triac on at the irst zero-voltage crossing following the initiation of the operting cycle. Thereafter, each gate pulse occurs as the triac voltage ncreases in magnitude to greater than 4 volts. This circuit tilizes the ZVS as a zero-voltage clock to initiate a change of the tate of the flip-flop at a zero-voltage crossing when the S or start witch is closed. The CA3083, a 5-transistor array, serves the ame function as the CA3018 in the previously described ircuits. In addition, Q2 is used as a triac gate current driver in an mitter-follower fashion. Within 8.3 milliseconds after the start

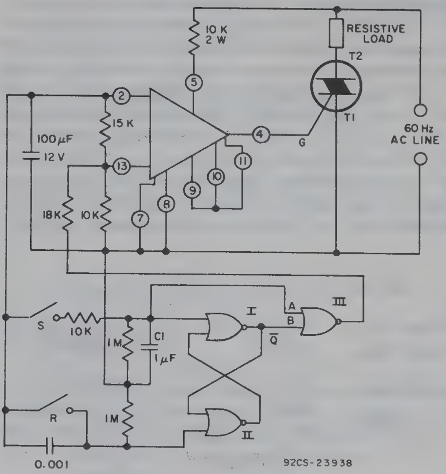

10 K
2 W
RESISTIVE
LOAD
T2
T1
G
60 Hz
AC LINE
2
5
4
13
7
8
9
10
11
15 K
100µF
12 V
18K
10K
S
10K
1M
C1
1µF
I
A
B
III
Q̄
R
1M
II
0.001
92CS-23938

Fig. 12—Solid-state circuit that accomplishes the function of the electromechanical circuit of Fig. 11.

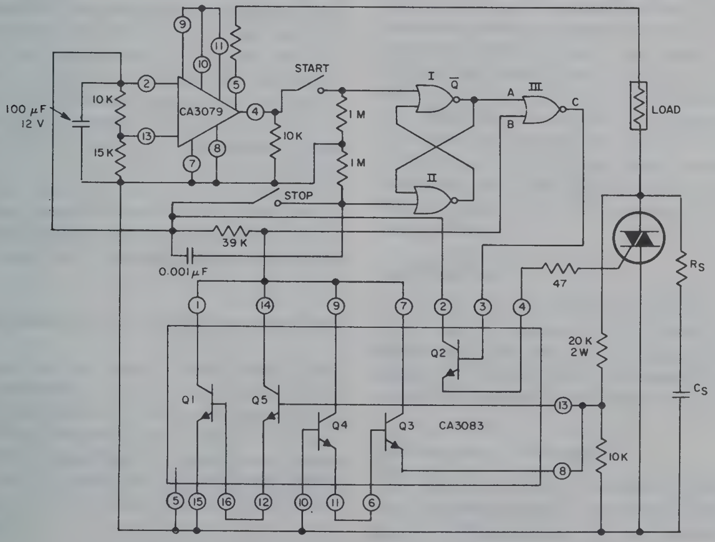

100 µF
12 V
10 K
15 K
2
13
9
10
11
5
4
7
8
CA3079
10K
START
STOP
1 M
1 M
I
Q̄
A
III
B
C
II
LOAD
39 K
0.001µF
47
1
14
9
7
2
3
4
Q2
Q1
Q5
Q4
Q3
CA3083
13
8
20 K
2 W
10K
RS
CS
5
15
16
12
10
11
6
92CM-23942

Fig. 13—Latching circuit that switches the triac on at the first zero-voltage crossing following initiation of the operating cycle.

switch is momentarily depressed, a pulse from the ZVS will change the state of the flip-flop, causing $\overline{Q}$ (A input to gate III) to go low. This change occurs within 2.4 volts of the zero-voltage crossing. The CA3083 circuit holds the B input of gate III at a high level until the triac T2 voltage approaches approximately 4 volts. At this time the CA3083 circuit clamps the B input of gate III to a low level and allows the gate III output to go to a high level. Transistor Q2 is biased on, which gates the triac on. As soon as the triac is latched on, the CA3083 circuit senses a low triac T2 voltage, approximately 2 volts, and causes the B input of gate III to go high and inhibit any additional gate drive to the triac. The inductive load causes a phase lag of current with respect to the line voltage. During the first half cycle of conduction, the triac will be on for more than one half cycle, as illustrated in Fig. 14. The beginning of the second and subsequent half cycles of conduction will be out of phase with the zero-voltage crossings. However, gate triggering will occur each time the T2 triac voltage is greater than the value of approximately ±4 volts until the reset or stop switch is momentarily closed. The reset does not depend on ZVS pulses as the triac inherently commutates off at zero current. Fig. 14 illustrates the time relationship of the various signals in the circuit of Fig. 13.

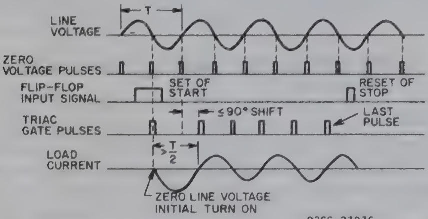


Fig. 14–Time relationship of various signals in the circuit of Fig. 13.

In each of the latching circuits incorporating a CA3059, an additional control input or feedback signal may be used to modulate a control function. One very common feedback function in machine controls is temperature. A thermistor may be substituted for one of the two resistors biasing terminal 13 of the zero-voltage switch, as shown in Fig. 4. This variable element will inhibit output pulses at terminal 4 whenever the voltage on terminal 13 is reduced below the voltage at terminal 9. This approach is not directly applicable to the circuit of Fig. 13; however, temperature feedback can be used to prevent initiation of a process control function with this circuit.

REFERENCE

"Features and Applications of RCA Integrated-Circuit Zero-Voltage Switches (CA3058, CA3059, CA3079)," A.C.N. Sheng, G. J. Granieri, J. Yellin, RCA Application Note ICAN-6182.

RCA
Solid State
Division

Thyristors and Rectifiers
Application Note
AN-6288

Thyristors in CD Ignition Systems

Capacitive-discharge (CD) ignition systems have been in use since the introduction of SCR's. The early recognition and application of the benefits of the SCR CD ignition in limited areas of the small-engine market (one-cylinder, two-and four-cycle engines, and marine engines) has since expanded to nearly 100 percent penetration of that market. Each day additional applications are added; chain saws, lawn mowers, snowmobiles, motorcycles, mini-bikes, fence chargers and auxiliary power sources are relying on the maintenance-free, high performance CD ignition system. Large-engine systems, such as the automotive CD systems have emerged as replacement-market product primarily for economic reasons. However, expansion in this area is expected to increase because of the energy crisis, which has stimulated the demand for greater fuel economy with improved performance. A third class of CD ignition system also relates to the energy crisis. The line-operated ignition system, or solid state pilot light used to ignite gas and oil burners in the home and industry, has taken on a new importance because of its reliable, energy-saving performance.

This Note describes the requirements of small-engine ignition systems (those deriving electrical energy from a flywheel alternator system), automotive or battery-powered systems, and the ac line-operated igniters. The merits of both capacitive and nductive systems are compared. Both systems are described in terms of performance and limitations. Practical circuits are hown.

BASIC CONSIDERATIONS FOR AUTOMOTIVE SYSTEMS

Under worst-case conditions, about 22 kilovolts are required o ignite the combustible mixture in the cylinder of an utomobile engine. In addition, a minimum energy of about 20 millijoules must be available in the spark to assure propagation of a stable flame front originating at the spark. The exact values f voltage and energy required under all operating conditions epend on many factors, including those described in the ollowing paragraphs.

Condition of Spark Plugs

Fouled plugs reduce both the voltage and the energy available for ignition. The plug gap also affects both the voltage and the energy required. As the plug gap is increased, the required voltage increases, but the required energy decreases.

Cylinder Pressure

The cylinder pressure depends on both the compression at the point of ignition and the air-fuel mixture. The minimum breakover voltage in any gas is a function of the product of gas pressure and electrode spacing (Paschen's Law). In automobile engines, the minimum voltage increases as this product increases. Therefore, higher pressures also require higher voltages. However, the energy required decreases as the pressure increases, and increases as the fuel-air mixture deviates from the optimum ratio. Worst-case conditions occur when the engine is started, at idle speeds, and during acceleration from a low speed because carburetion is poor and the fuel-air mixture is lean. The combination of a lower cylinder pressure and a dilute fuel-air mixture under these conditions results in a high energy requirement.

Spark Plug Polarity

The center electrode of the spark plug is hotter than the outside electrode because of the thermal resistance of the ceramic sleeve that supports it. If the center electrode is made negative, the effect of thermionic emission from this electrode can reduce the required ignition voltage by 20 to 50 percent.

Spark Plug Voltage Waveshape

The spark plug voltage waveshape is shown qualitatively in Fig. 1. The voltage starts to rise at point A and reaches ignition at point B. The region from B′ to C represents the sustaining

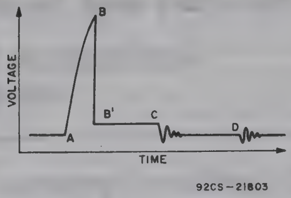


Fig. 1 – Ignition-voltage waveshape.

voltage for ionization across the spark plug. When there is insufficient energy left to maintain the discharge (at point C), current flow ceases and the remaining energy is dissipated by ringing. The final small spike at point D occurs when the ignition coil again starts to pass current.

The two most important characteristics of the voltage waveshape are its rise time (from A to B) and the spark duration (from B′ to C). A rise time that is too long results in excessive energy dissipation with fouled plugs; a rise time that is too short can lead to loss by radiation through the ignition harness of the high-frequency components of the voltage. The minimum rise time should be about 10 microseconds; a 50 microsecond rise time is acceptable. Conventional systems have a typical rise time of about 100 microseconds. It should be noted that, at an engine speed of 5000 revolutions per minute, one revolution takes 12 milliseconds. Engine timing accuracy is usually no better than 2 degrees, which corresponds to 67 microseconds. The error caused by the rise time is therefore comparable to normal timing errors. At normal cruising speeds (about 2000 revolutions per minute), the 2-degrees timing error corresponds to about 165 microseconds, and rise-time effects are negligible.

Energy Storage

The energy delivered to the spark plug can be stored in either an inductor or a capacitor. Although the inductive storage method is the more common approach, both are used; both are discussed below. One requirement common to both methods is that, after the storage element is discharged by ignition, it must be recharged before the next spark plug is fired. For an eight-cylinder engine that has a dwell angle of 30 degrees, the time τ between ignition pulses (in milliseconds) is equal to 15,000 divided by the engine r/min, and the time t_{on} during which the points are closed is equal to 10,000/r/min. When the engine r/min is 5000, t_{on} is 2 milliseconds. Therefore, the charging time constant for either an inductive or a capacitive storage system should be small compared to 2 milliseconds.

INDUCTIVE-DISCHARGE AUTOMOTIVE SYSTEM

Fig. 2 shows the basic circuit for an inductive-discharge system. The total primary-circuit resistance (ballast plus coil) is represented by R_p; the primary inductance of the coil is represented by L_p. Switch S represents the points in a conventional system. The step-up turns ratio of the transformer is N. When the points close, current increases exponentially with a time constant t_L equal to L_p/R_p. The maximum primary current I_p is equal to V_{BAT}/R_p, and the energy e_L stored in the coil is equal to $L_pI_p{}^2/2$. When the points open, a voltage V_p is generated across the primary terminals; this voltage is equal to $-L_p(dI_p/dt)$, where I_p is the primary current as a function of time t. The secondary voltage V_s, which is delivered to the spark plugs through the distributor, is equal to NV_p.

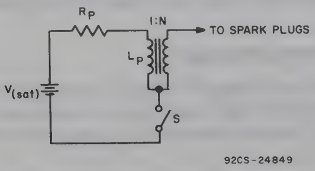


Fig. 2 – Basic inductive-discharge ignition circuit (Kettering system).

The maximum current is limited to about 4 amperes by possible burnout of the points. The total energy stored in the coil must be about 50 millijoules to provide for energy losses by radiation, fouled plugs, and the like. For a battery voltage of 12 volts and a primary-circuit resistance of 3 ohms, L_p must have a value of about 6 millihenries. The time constant t_L is then about 2 milliseconds; the coil current does not reach its maximum value at high engine speeds. Fig. 3 shows primary current and secondary voltage as a function of engine speed for a typical non-transistorized ignition circuit. The degradation in secondary voltage follows the primary current. The available energy decreases even more rapidly because it is proportional to the square of the current. This problem can be even more severe than indicated because some conventional ignition coils have inductances as high as 12 millihenries, and the time constant is correspondingly longer.

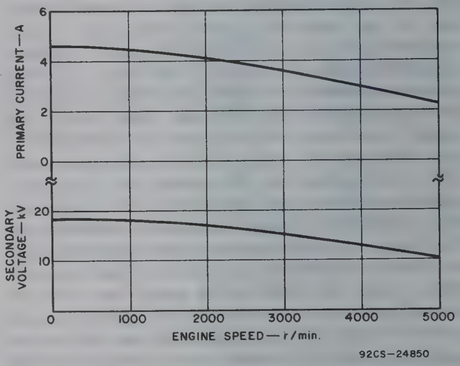


Fig. 3 – Performance of conventional inductive-discharge ignition system.

CAPACITIVE-DISCHARGE SYSTEMS

The basic capacitive-discharge system is illustrated in Fig. 4. It is important to note that the transformer serves simply as a pulse transformer. Therefore, performance at high engine speeds is not affected by the primary inductance of the transformer but, instead, is governed by the time required to charge capacitor C to the desired voltage level.

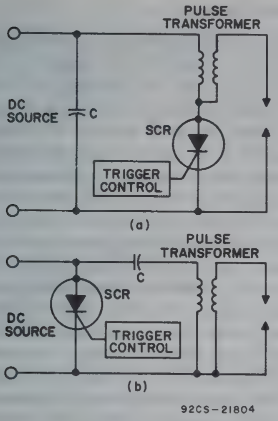


Fig. 4 – Basic configuration for capacitive-discharge ignition circuits: (a) storage capacitor connected across input voltage source; (b) storage capacitor connected in series with input voltage source and pulse transformer.

Basic Circuit Operation

The trigger control circuit (which can be a transistor switch) is controlled by the distributor points. More sophisticated distributor control, such as that available from distributors in which the voltage pulses are derived magnetically or photo-optically, can also be used to control the trigger circuit. The capacitor is charged to the dc voltage; the stored energy e is equal to $C(V_C)2/2$, where V_C is the capacitor voltage. At the appropriate time, the trigger control circuit fires the SCR. The capacitor discharges through the transformer, which steps up the voltage to a value V_S equal to KNV_S. N is the transformer turns ratio and K is a constant that is dependent mainly on the value of the capacitance and of the transformer leakage inductance, and generally ranges between 1 and 1.5. The stored energy is thus delivered to the spark plug in the form of a high-voltage pulse. Typical values for V_C and C are about 350 volts and 1 microfarad, respectively. Thus, the energy e is about 60 millijoules.

Because the energy dissipated in the spark gap is equal to the energy stored in the capacitor minus the losses in the transformer and SCR, the energy available in the system is relatively easy to calculate. Examination of the basic circuits shows that the energy is transferred only when the SCR is forward conducting with the gate biased on. However, part of the energy is not available in the basic circuit because the capacitor and inductor form a tuned circuit when the SCR is on, and the energy that would normally flow back from the inductor to the capacitor is stopped by the high reverse impedance of the SCR. This energy is, therefore, lost as available spark energy. The duration of the spark is limited, then, to approximately one-half cycle of the natural LC frequency of oscillation.

Some of the energy lost can be regained and used to increase the spark duration by installing a diode in the basic circuit of Fig. 4 as shown in Fig. 5. The diode not only bypasses the reverse impedance of the SCR but eliminates the possibility that the SCR might conduct in the reverse direction should the gate of the SCR be biased on at this time. Thus, in addition to improving the low-temperature performance of the system by increasing spark duration, the diode reduces the possibility of excessive heating and damage to the SCR that could accompany reverse conduction, and thereby reduces the overall cost of the system by reducing the reverse blocking requirement of the SCR. The ratio of spark duration to charging time decreases with increasing r/min, so that in some applications an r/min limit may be reached which is below the desired maximum because of charging-time requirements.

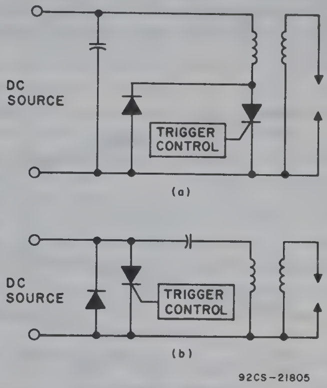


Fig. 5 – Basic circuit configurations shown in Fig. 4 modified by the addition of a diode in shunt with the SCR switching device.

CAPACITIVE VS INDUCTIVE SYSTEMS

Economic Considerations

The capacitive-discharge system is generally acknowledged to be technically superior to the inductive-discharge system. Its chief disadvantage is economic. Although the transformer may be less expensive than an ignition coil, the capacitor must be of fairly high quality. The SCR and its associated trigger circuit are generally more expensive than comparable transistors and trigger circuits for inductive-discharge systems. Finally, the capacitor charging circuit in an automotive ignition system is a dc-to-dc converter, which represents an additional cost element. Such converter circuits typically require a transformer, two or four diodes for rectification, and one or two transistors. With the increasing use of ac alternators in automobiles, it may eventually be possible to tap off the ac voltage, step it up to the desired voltage by use of a simple transformer, and rectify it. However, it is not clear at this time that this approach is desirable or less costly. Despite these considerations, there are a number of capacitive-discharge systems available on the replacement market.

Technical Considerations

An important advantage of the capacitive-discharge system is that the input power increases in direct proportion with the increased spark plug power required as engine speed increases. In the inductive-discharge system, on the other hand, the opposite is true, as shown in Fig. 6. The required power is the product of the energy required per ignition pulse and the number of ignition pulses per second. The upper curve of Fig. 6 was determined experimentally for the circuit of Fig. 2 for a battery supply of 14 volts. In the capacitive-discharge system, input power can be made proportional to the required spark plug power because the capacitor is charged once per ignition pulse and holds this charge until needed. In addition, feedback can be used to turn the converter off after the capacitor is charged and, thus, to cut off the input power to the system. The input power can therefore be made proportional to engine speed, and higher efficiency can be achieved at all speeds. The curve shown in Fig. 6 applies for a commercially available capacitive-discharge system. The higher efficiency of this system is apparent.

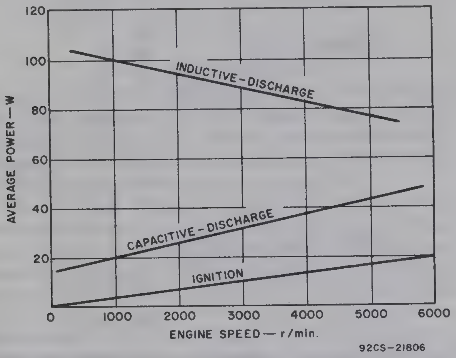


Fig. 6 – Ignition power requirements

A second important advantage of the capacitive-discharge system is that faster rise times are more readily obtained because the transformer acts only as a pulse transformer and not as an energy storage element. Therefore, its high-frequency response characteristic is governed by its leakage inductance, which is much smaller than the primary magnetizing inductance. This advantage is obtained even when a conventional ignition coil is used as the pulse transformer. Secondary voltage rise times of approximately 15 to 30 microseconds are readily obtained. As discussed previously, the shorter rise time greatly enhances the ability of this system to fire fouled plugs.

A major operating point that must be considered in the capacitive discharge system is when to charge the capacitor. In some systems the capacitor is charged soon after discharge, in others, just before discharge. The second method is the better in that it minimizes the losses resulting from leakage, but this advantage is somewhat negated because of the precise timing required to institute the charge just prior to discharge. This requirement can result in complex mechanical or electrical arrangements.

Component Requirements

The reliability and performance of CD circuits depend heavily on the proper rating of the SCR and the quality of the storage capacitor. Because the specifications and characteristics of the spark coil are usually known, the design of an ignition circuit is usually begun there; the spark duration and energy required determine the size of the capacitor and the charging voltage. Once the charging voltage and capacitor size are known, the rate of change of current can be determined as well as the peak current which occurs in the capacitor-SCR-coil circuit. The maximum temperature just prior to and during operation of a CD circuit is, perhaps, the most important consideration in characterizing the SCR for the circuit, as these conditions dictate the permissible forward-blocking leakage level at the required blocking voltage. A leakage level which becomes excessive will discharge the voltage on the storage capacitor rapidly, and adversely affect performance. This condition is of particular concern during starting of a hot system because cranking speeds are slow, and engine temperatures may be higher than normal running temperatures.

Economic trade-offs in component selection should be considered at this point. A higher charging voltage may be considered to permit the use of a high-voltage regulator to compensate for leakage in both the capacitor and SCR. A circuit designed to charge the capacitor just prior to discharge would also tolerate a higher level of leakage current in the SCR. However, the rate at which the capacitor is charged is limited by the capability of the SCR to withstand practical amounts of static dv/dt at the worst-case temperature. Low-temperature operating limits require consideration of gate-firing characteristics. The SCR gate voltage and, to a greater degree, the gate current required, increase as temperature decreases. Gate-current sensitivity must be kept to a low enough level at high-temperature extremes to avoid spurious or false turn on. This sensitivity establishes the gate current requirement at the low-temperature extreme. In most CD applications, minimum and maximum gate-current requirements are specified at 25°C and are correlated with minimum and maximum limits at the temperature extremes of operation.

The SCR parameter values that must be specified to assure reliable operation in ignition circuits are shown in Table I. To

TABLE I – SCR PARAMETER VALUES OF IMPORTANCE IN IGNITION CIRCUITS

I_{DROM}	when $V_D = V_{Capacitor} + 20\%$ at a case temperature T_C of 100°C.
I_{RRDM}	when V_R = 25 volts when using a diode as in the circuit of Fig. 5. or when $V_R = V_{peak\ reverse}$ due to flywheel effect in the flywheel charged system. In both cases, T_C is 100°C.
V_T	when $I = I_{peak}$, the value of V_T is approximately 2.5 to 4 volts depending on current pulse amplitude, repetition rate, and case temperature.
V_{gate}	at 12 volts with R_A = 30 ohms. V_{gate} and I_{gate} will be maximum or minimum limits depending on trigger-circuit requirements. Higher limits help prevent spurious firing as a result of noise.

determine the rate of rise of charging voltage, the relationship i = C dv/dt can be applied to the charging circuit values. During discharge of the capacitor, the rate of rise of discharge current, the peak anode current, and the maximum repetition rate must not exceed the ratings of the SCR: Ipk = E_{cap}/ LC, di/dt = Ipk/2/T_1, as illustrated in Fig. 7. The repetition rate is determined by the average power dissipation and the maximum junction temperature for worst-case high-temperature operation.

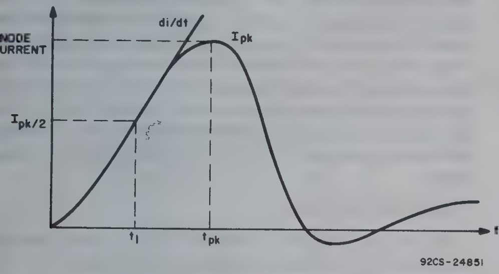


Fig. 7 – SCR ratings.

The ignition coil used in the capacitive-discharge circuit can be a specially wound, low-inductance unit or the existing coil. The existing coil has an advantage in that it can be used with a breaker-point distributor to provide the ignition function in the event of an electronic failure. The major disadvantage of the use of the existing coil is that the benefits of ignition pulses with sharp rise times, the type of pulses needed to fire fouled spark plugs, are reduced because of the inductance of the coil. Because of the ease of obtaining a trigger pulse and the circuit simplicity, the SCR capacitive-discharge system is used almost exclusively on small engines.

TYPES OF CAPACITIVE-DISCHARGE SYSTEMS

There are three systems in which capacitor-discharge ignition circuits can be used to good advantage: the flywheel-charged small-engine system, the inverter-charged system such as that used in automotive and stationary engine systems, and the line-charged ignitor used with gas-operated appliances such as dryers and furnaces. All of these systems are operated similarly: energy stored in a capacitor is transferred to a spark gap through a transformer and SCR; the SCR assures a short-duration spark.

The circuit of Fig. 8 is typical of that used in the three systems.

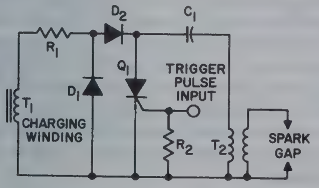


Fig. 8 – Typical circuit configuration for a capacitive-discharge ignition system.

The ac potential across transformer T_1 is rectified by diode D_2, and charges capacitor C_1 to the required voltage. Resistor R_1, which may be part of the charging-winding resistance, limits the current and prevents the SCR from firing as a result of the imposition of a dv/dt value in excess of the capability of the SCR. The combination of diodes D_1 and D_2 prevents the charging winding of transformer T_1 from impressing a high reverse voltage across the SCR. Resistor R_2 damps variations in the input impedance of the SCR. The SCR is triggered at the appropriate time, and the energy stored in the capacitor is transferred into the primary of T_2, thus causing a spark at the spark gap. The voltage required to break down the spark gap is a function of the spacing of the electrodes and pressure in the cylinder in the vicinity of the gap. The spark in the gap lasts until the value of current passing through the SCR is below its holding current. When the SCR stops conducting, D_1 and D_2 start conducting in the reverse direction and lengthen spark duration. After the SCR turns off, C_1 is discharged, and the circuit is ready to repeat the cycle.

Flywheel-Charged Systems

Some of the simplest ignition systems are constructed using the flywheel-charging method as this method affords a reliable circuit with a minimum of active components. The system makes use of a rotating magnetic field to charge the capacitor and to trigger the SCR; mechanical position determines timing. The designer has several options in the determination of when the charging of the capacitor takes place in the flywheel system. The most advantageous time occurs just before the capacitor is to be discharged. However, some voltage regulation problems must be considered. Because V = Ndϕ/dt where dϕ and N are constant, the voltage produced across the charging winding varies with r/min. At low flywheel speeds, there may not be enough voltage available to produce the energy required; at high flywheel speeds, it is possible to have too high a voltage and therefore to exceed the voltage breakdown rating of the SCR and cause premature triggering. If the breakdown voltage rating of the capacitor is also exceeded, the capacitor will be damaged. Therefore, some means of accommodating or regulating the voltage must be considered.

The design of the trigger coil is also important. It must be capable of providing voltages and currents high enough to gate the SCR into conduction at all temperatures. In addition, consideration should be given to the fact that the gate pulse should end before the current through the SCR ceases to flow so that the device is not gated during the period of reverse voltage.

As is evident in the above discussion, a major factor in the performance of the flywheel ignition circuit is the design of the magnetic components used for the triggering and charging functions. A typical example of a fly-wheel charged ignition circuit is shown in Fig. 9.

Regulation of the charging voltage may be accomplished with a zener diode or an SCR. The zener-diode method in Fig. 10 regulates by clamping the charging voltage to a set level. However, dissipation within the zener may be difficult and costly to contend with in some applications. The SCR regulator in Fig. 11 provides a crowbar mode of regulation which

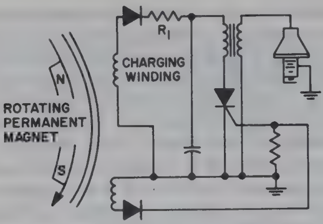


Fig. 9 – Flywheel-charged igniter circuit.

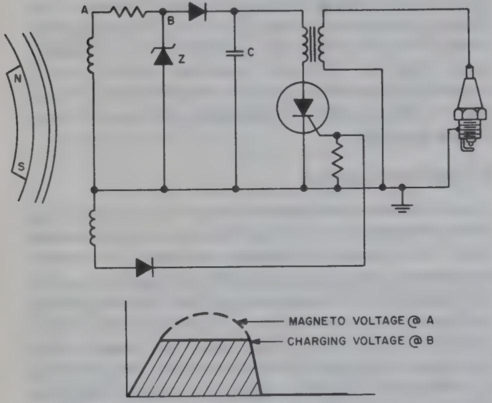


Fig. 10 – Zener-diode regulator.

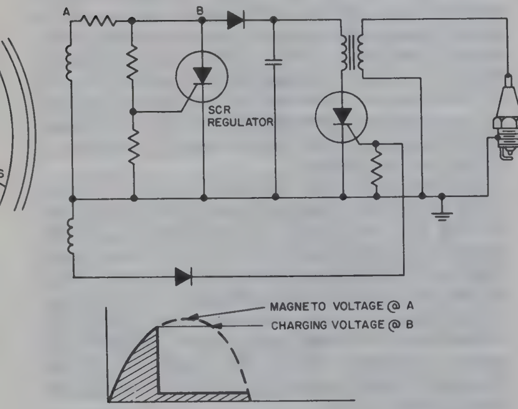


Fig. 11 – SCR regulator.

dissipates a minimum of power but requires additional gate triggering circuitry. In most flywheel charging systems, the open-circuit charging voltage may approach 1000 volts. In the event of an open gate circuit or malfunctioning trigger coil, the capacitor voltage will tend to build up toward the open-circuit charging voltage and cause damage to the charging components, capacitor, or SCR if the charging voltage is not regulated.

Because of the inherent simplicity of flywheel-charged systems, a gate trigger pulse can be easily generated from a flywheel magnet and pick-up coil. The shape of the magnetic core of the pick-up coil can be tailored to provide multiple pulses for gating. Air gap and core size can be formed as in Fig. 12 to provide an earlier than normal gate pulse of very low amplitude at low flywheel speeds. As engine speeds build up, the amplitude of the earlier gate pulse will be sufficient to trigger the SCR. In this manner, an automatic timing advance can be designed into the CD system. In small engines, which are usually hand started, this automatic timing advance provides easier "no kick" starting with timing advanced once the engine reaches normal running speed.

Inverter-Charged Systems

A system that eliminates the need for flywheel magnetics is the inverter-charged system. This system is used where a battery is available, such as in an automobile.

There are some practical considerations which limit the use of the inverter system. The first limitation is starting under low temperature. At an ambient temperature of –40°C, the available battery voltage in a "12-volt" automotive system (12-volts nominal at 25°C) may be as low as 6 volts dc because of the starter current required at this temperature and the reduced battery capability. In addition, at this temperature, the fuel-air mixture is wet, particularly in a two-cycle engine. For reliable starting, the full spark energy must be available immediately. This means that the inverter must be capable of producing the full energy at low supply voltages. The voltage step-up ratio of the system transformer is constant and therefore cannot be increased as the temperature decreases; such an action would assure sufficient voltage at low temperatures, but would subject the capacitor and SCR to voltages in excess of their ratings under normal conditions and after starting. The problem of starting at low temperature may be circumvented by regulating the voltage on the capacitor or by using a transformer with a higher step-up ratio than required and then shutting down or removing the inverter, with its transformer, from the circuit at a time that will prevent any voltages from becoming a problem.

As the maximum r/min of the engine increases, the demands on the inverter also increase; this variation in demand can be alleviated by ballasting. When ballasting of the ignition is accomplished by means of a regulator circuit, external ballasts are not needed. A typical example of an inverter-type ignition system with regulator ballasting is shown in Fig. 13. The trigger circuit shown in the figure is subject to the same variations in potential as the inverter circuit in addition to others arising from the need to gate the SCR with a high-current at low temperature when the available voltage is low. This gating problem can only be solved by a compromise between overdriving of the gate at high temperature and maintaining only an adequate drive at low temperatures; there are many circuits that can be used to achieve this compromise.

The inverter must be capable of handling a power level, typically between 20 and 50 watts, representing an energy level of 80 millijoules per pulse, for a 4-cycle, 8-cylinder engine. The

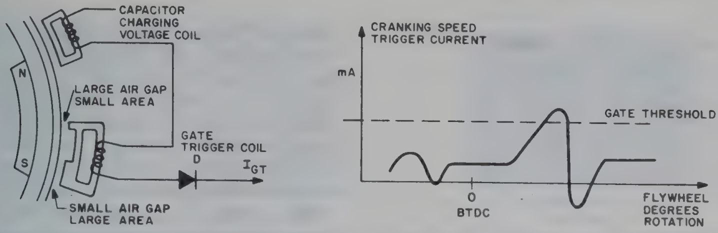

CAPACITOR CHARGING VOLTAGE COIL
N
S
LARGE AIR GAP SMALL AREA
GATE TRIGGER COIL
D
I_{GT}
SMALL AIR GAP LARGE AREA
CRANKING SPEED TRIGGER CURRENT
mA
GATE THRESHOLD
0
BTDC
FLYWHEEL DEGREES ROTATION
92CM-24854

Fig. 12 – Magnetic advance for flywheel-charged capacitive-discharge system.

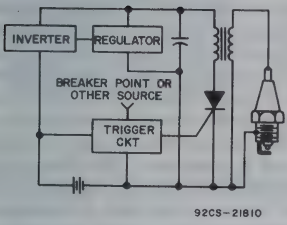
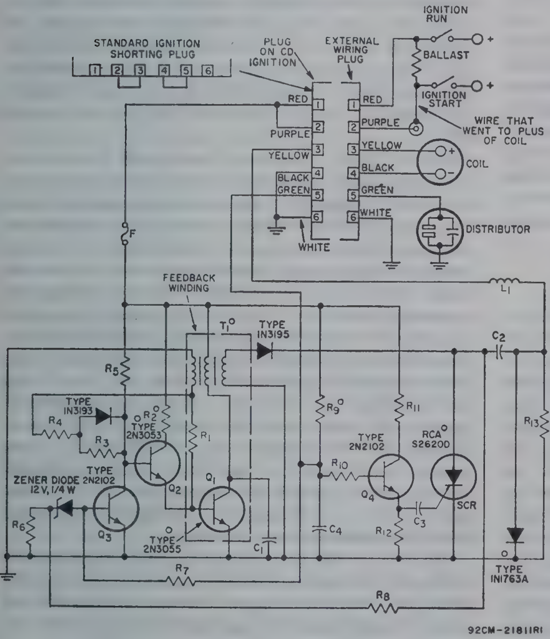

INVERTER
REGULATOR
BREAKER POINT OR OTHER SOURCE
TRIGGER CKT
92CS-21810

Fig. 13 – Block diagram of an inverter-charged ignition system.

inverter circuit should operate at a frequency high enough to make use of smaller transformer-core sizes and yet be able to incorporate low-cost power devices. The RCA line of hometaxial power transistors is generally very reliable and economical in inverter ignition systems.

CAPACITIVE-DISCHARGE AUTOMOTIVE IGNITION SYSTEM

Fig. 14 shows the circuit diagram for a low-cost transistor/SCR capacitor-discharge ignition system for passenger automobiles. This system offers the advantages of reduced maintenance,


STANDARD IGNITION SHORTING PLUG
1 2 3 4 5 6
PLUG ON CD IGNITION
EXTERNAL WIRING PLUG
IGNITION RUN
BALLAST
IGNITION START
WIRE THAT WENT TO PLUS OF COIL
RED
PURPLE
YELLOW
BLACK
GREEN
WHITE
COIL
DISTRIBUTOR
F
FEEDBACK WINDING
T_1°
TYPE 1N3195
C_2
L_1
R_5
TYPE 1N3193
R_4
R_2°
TYPE 2N3053
R_3
R_1
R_9°
R_{11}
TYPE 2N2102
RCA° S2620D
R_{13}
TYPE 2N2102
ZENER DIODE 12 V, 1/4 W
Q_2
Q_1
R_{10}
Q_4
SCR
R_6
Q_3
TYPE 2N3055
C_1
C_4
R_{12}
C_3
R_7
R_8
TYPE 1N1763A
92CM-21811R1

$C_1 = 0.25\ \mu F$, 200V
$C_2 = 1\ \mu F$, 400V
$C_3 = 1\ \mu F$, 25V
$C_4 = 0.25\ \mu F$, 25V
F = 5A
$L_1 = 10\ \mu H$, 100T of No. 28 wire are wound on a 2W resistor (100 ohms or more)
R_1 = 1000 ohms
R_2 = 50 ohms, 5W
R_3 = 22000 ohms
R_4 = 1000 ohms
R_5 = 10000 ohms
R_6 = 15000 ohms
R_7 = 8200 ohms
R_8 = 0.39 megohm
R_9 = 220 ohms, 1W
R_{10} = 1000 ohms
R_{11} = 68 ohms
R_{12} = 4700 ohms
R_{13} = 27000 ohms

T_1 = Transformer, wound as follows: A ½ in. bobbin ando EI stack of grain oriented silicon steel are used; first, 150 turns of No. 28 wire are wound and labeled start 1 and finish 1 on the winding; second, 50 turns of No. 24 and No. 30 wires are wound bifilar and labeled start 2 and finish 2; third, 150 turns of No. 28 wire are wound and labeled start 3 and finish 3. All windings are wound in the same direction. A total air gap of 70 mil (35 mil spacer) is used. Connections are made as shown in Fig. 783.

All the resistors are ½W unless otherwise indicated

° These components are subject to excessive temperature rise unless provision is made to transfer the heat to the ambient air by means of an appropriate heat sink.

Fig. 14 – An SCR capacitive-discharge automotive ignition circuit.

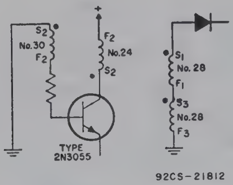


Fig. 15 – Details of inverter transformer (T1) shown in Fig. 14.

smaller current drain on the automobile battery, full output voltage at low battery voltage (down to 4 volts), and a high-voltage output pulse that has a rapid rate of rise. As pointed out previously, this latter factor provides greater assurance of the firing of fouled spark plugs.

The SCR ignition system is essentially a combination of eight basic circuit units, as follows: (1) A single-ended, self-oscillating swinging-choke inverter is used to provide the dc-to-ac inversion and the step-up of the battery voltage. (2) An output circuit that includes an SCR, a storage capacitor, an ignition coil (a standard automotive ignition coil is used), and a commutating diode develops the fast-rising high-voltage pulse for the spark plugs. (3) The commutating diode and a single rectifying diode form a capacitor-charging circuit to transfer energy from the inverter to the output-circuit storage capacitor. (4) A regulator stage controls the frequency of the inverter stage to provide efficient regulation of the voltage across the storage capacitor. (5) A protection circuit (limiting inductance and resistance) prevents damage to the system by transients that may be developed in the case of an open or shorted ignition coil or because of high-voltage arcing to either primary terminal of the ignition coil. (6) A shutdown circuit holds the inverter inoperative when the ignition breaker points are open. (7) A trigger circuit suppresses the normal bounce of the breaker points and also prevents SCR triggering by the residual voltage across the closed points. (8) A method of SCR commutation is used that involves the interplay of several parts of the overall system.

Inverter, Regulator, and Capacitor-Charging Circuit

The inverter uses a 2N3055 transistor (Q_1) in a single-ended output stage, a 2N3053 transistor (Q_2) in an emitter-follower driver stage, and a 2N2102 transistor (Q_3) in a control stage that is part of the shutdown circuit which holds the inverter inoperative when the ignition breaker points are open. Regenerative feedback is coupled from the feedback winding of the inverter output transistor T_1 back to the bases of the driver and output transistors. The high gain provided by the combination of transistors Q_1 and Q_2 assures oscillation and low drive-power requirements for the inverter. The starting resistor R_5 provides a forward bias that drives transistors Q_1 and Q_2 into conduction to initiate oscillation in the inverter. The regenerative action of the circuit very quickly drives the output transistor Q_1 into conduction, and essentially the full battery voltage is then applied across the primary of the inverter output transformer T_1. The resultant current increase in the transformer primary winding induces a voltage across the feedback winding that supplies sufficient current through resistors R_1 and R_4 and diode D_1 to maintain the output transistor Q_1 in saturation. During this part of the operating cycle (i.e., during the conduction of transistor Q_1, the voltage across the secondary winding of transformer T_1 reverse-biases the rectifying diode D_2 in the capacitor-charging circuit, and no energy is transferred to the output circuit of the ignition system.

With transistor Q_1 operating with fixed base current (in saturation), its collector current rises to a value beyond which it cannot increase. As a result, the feedback voltage is decreased, and no longer maintains base drive to transistor Q_1, and the transistor starts to turn off. The regenerative action of the inverter circuit causes a rapid reversal of the base drive for transistors Q_1 and Q_2. These transistors, therefore, are quickly cut off, and a "flyback" voltage pulse is generated at the collector of the output transistor Q_1. Diode D_3 blocks the reverse voltage and limits the reverse base drive. The reverse-bias current that turns off transistors Q_1 and Q_2 is applied through resistors R_3 and R_1, respectively. The flyback-pulse voltage is stepped up across the secondary of transformer T_1. The polarity of this pulse, however, is such that the rectifying diode D_2 becomes forward-biased. As a result, the energy previously stored in the primary winding of transformer T_1 is transferred through the secondary winding, rectifying diode D_2 and commutating diode D_3 to charge the output-circuit storage capacitor C_2. The capacitor C_1 connected across transistor Q_1 reduces the amplitude of the leakage-inductance pulse and restricts the rate of rise of the collector voltage of transistor Q_1. The charging current for capacitor C_2 is shunted around the ignition coil by the commutating diode D_3 so that no energy is transferred into the ignition coil and from there to the spark plugs.

When the collector voltage of transistor Q_1 decreases to a value less than the battery voltage, it again begins to conduct, and the cycle is repeated to charge the storage capacitor C_2 to a higher voltage. Until the voltage across the storage capacitor rises above a predetermined value, the voltage applied to the zener diode D_4 from the voltage divider formed by resistors R_6 and R_8 is insufficient to cause the zener diode to conduct. If the ignition breaker points are closed during this time, resistor R_7 is returned to ground and transistor Q_3 cannot conduct. When the capacitor voltage rises to a level high enough to cause zener diode D_4 to conduct, transistor Q_3 turns on and shunts base drive current from transistor Q_2. This effect reduces the base drive of transistor Q_1 and causes this transistor to pull out of saturation at a lower collector-current level which, in turn, increases the frequency of oscillation. The cutback in peak primary current reduces the charging rate of the storage capacitor C_2 to the level required to replenish circuit losses and prevents further rise in the output voltage.

Transistor Q_3 also holds the inverter inoperative when the ignition breaker points are open. When these points open, the current fed from the voltage at the breaker points through resistor R_7 causes transistor Q_3 to conduct heavily. This effect shorts the base of transistor Q_2 and stops the oscillation.

Fig. 16 shows that the collector voltage of transistor Q_1 swings alternately between the saturation level and the peaks of flyback pulses of increasing amplitude. The change in frequency that results from regulator action is apparent in the voltage waveform. The collector voltage then decreases to the supply voltage when the ignition breaker points open and shut down the inverter. Fig. 17 shows an expanded view of the turn-off and flyback characteristics of transistor Q_1 at a point when the storage capacitor is being charged.

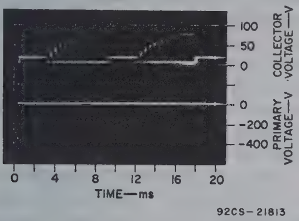


Fig. 16 – Collector voltage of the inverter output transistor Q1 (top) and ignition-coil primary voltage (bottom) as functions of time (2000 r/min; V_{CC} = 12 V).

Output Circuit

When a high voltage pulse is required, the RCA S2620D SCR in the output circuit is gated on. As a result, the anode voltage of the SCR decreases to approximately zero, and the voltage across the charged storage capacitor is applied to the primary of the ignition coil. (The value of the inductance L_1 is negligible in comparsion to the inductance of the ignition coil and is not considered in this analysis.) The ungrounded (+) side of the ignition-coil primary (terminal 3 on the connecting plug) is driven negative with respect to the capacitor potential. Diode D_3, in parallel with the coil, is reverse-biased at this time. The discharge of the capacitor into the primary of the ignition coil generates a high-voltage pulse across the secondary.

The capacitor discharges into the primary inductance of the ignition coil and builds up the primary current in the coil. When the voltage across the capacitor (and coil primary) decreases to zero and starts to reverse, the commutating diode D_3 becomes forward-biased and begins to conduct. The current through the primary of the ignition coil is at a peak at the time the diode begins to conduct. The current then suddenly switches out of the SCR and into the diode. The primary-coil voltage remains clamped at zero, and the primary current decays at a rate determined by the L/R ratio of the coil. Because of the clamping action of the commutating diode D_3 the duration of the spark in the spark plug is lengthened.

When the SCR is on, it effectively places a short across the secondary of the inverter transformer. However, the inverter is off when the SCR is on (because of the shut-down circuitry); the inverter, therefore, does not operate into the short.

Figs. 18 and 19 show the SCR voltage and current as a function of time. The starting point of the waveform shown in Fig. 18 occurs at the instant the ignition points open. The anode voltage of the SCR decreases to zero and the anode current builds up to the peak value in a quarter cycle. The current is then switched out of the SCR, and SCR current decreases suddenly almost to zero. The small residual current is a result of the energy stored in the inverter transformer during the period that the inverter is inoperative. This stored energy causes a current to circulate from the secondary of the transformer through the SCR. When the ignition points close and the capacitor recharges, the SCR blocks the voltage on the capacitor.

The starting point for the waveform shown in Fig. 19 occurs at the instant that the ignition points close. The period between the instant at which the points close and that at which the voltage first begins to rise is the time during which the collector current of transistor Q_1 builds up to the switching level. The significance of this time is explained subsequently during the discussion on commutation of the SCR.

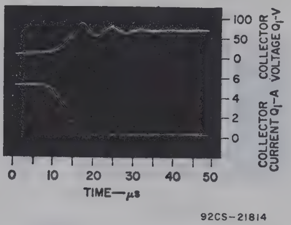


Fig. 17 – Expanded collector voltage (top) and current (bottom) of the inverter output transistor (Q1) as functions of time during turn-off when the storage capacitor (C2) is being charged (V_{CC} = 12 V).

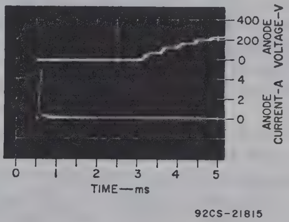


Fig. 18 – SCR voltage (top) and current (bottom) as a function of time (2000 r/min; V_{CC} = 12 V).

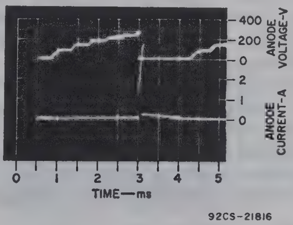


Fig. 19 – SCR voltage (top) and current (bottom) as a function of time (oscilloscope sweep triggered at instant ignition breaker points are closing; 4000 r/min; V_{CC} = 12 V).

Fig. 20 shows the waveforms for voltage and current in the primary of the ignition coil that result when a 7-millihenry inductor is used to simulate the primary of the ignition coil. The primary voltage increases rapidly to a peak negative value, then decays sinusoidally to zero as the current builds to a peak. The primary voltage is then clamped at zero, and the current decays exponentially.

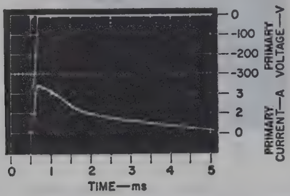


Fig. 20 – Primary voltage (top) and current (bottom) as a function of time (1-mH coil used in place of standard ignition coil; 2000 r/min; V_{CC} = 12 V).

It should be noted that an actual ignition coil, operated with the secondary open, will reflect a tuned circuit into the primary. This operation causes a ringing on top of the waveforms, as shown in Fig. 20. The anode voltage of the SCR may actually reverse for a short time because of this ringing. The SCR essentially blocks this reverse voltage except for a small current that flows because of the presence of positive gate signal. As a result, some instantaneous dissipation occurs in the reverse-blocking function of the SCR. The SCR can safely withstand this dissipation for the short period of time required. The gate signal is kept positive through the ringing cycle so that the SCR continues to conduct when the anode voltage rings back positive. This ringing does not occur when the secondary voltage fires a plug because the ionized plug shorts the secondary winding.

Protection Circuit

Inductance L_1 is used to protect the system against a shorted primary in the ignition coil. The limiting inductance controls the rate of change of current (di/dt) and peak current that occurs when the SCR is turned on with a short across the primary of the ignition coil. Resistance R_{13} is used to assure that the voltage across the primary of the ignition coil is not negative when the coil is open. If this voltage were not clamped, the regulator would not operate properly, and the peak collector voltage of transistor Q_1 would exceed the limits specified for the device.

Trigger Circuit

The triggering circuit performs the following functions: (1) triggers and holds the SCR on when the ignition points open (at battery voltage down to 4 volts), (2) applies a signal back into the inverter shutdown circuitry when the ignition points are open, (3) suppresses the inverter signal that rides on the power supply so that it does not trigger the SCR, (4) prevents the residual voltage across the closed points from triggering the SCR, (5) prevents normal point bounce that occurs when the points close, and (6) maintains proper operation whether or not the capacitor is present across the breaker points. The 2N2102 transistor Q_4 is used to perform these functions.

The trigger current for the gate of the SCR is initiated when the base voltage of transistor Q_4 reaches approximately 0.6 volt above the emitter voltage. The trigger current flows from the supply through resistor R_{11}, transistor Q_4, and capacitor C_3 to the gate of the SCR.

When the ignition points open, capacitor C_4 (and the capacitor across the points) charges because of the current through resistor R_3. If the points are open long enough (without bouncing), the voltage across capacitor C_4 becomes high enough to turn on transistor Q_4. The voltage required to turn on transistor Q_4 is the sum of the gate-cathode voltage of transistor Q_5, the voltage across capacitor C_3, the emitter-base voltage of transistor Q_4, and the voltage drop across resistor R_{10}. (Resistor R_{10} ensures that the voltage across the open ignition points rises to a value high enough to supply sufficient current through resistor R_7 to shut down the inverter.) At normal engine speeds, the average voltage level across capacitor C_3 keeps both the gate-cathode junction of the SCR and emitter base junction of the transistor reverse-biased until capacitor C_4 charges high enough to turn on transistor Q_4. Because transistor Q_4 is off and the gate of the SCR is reverse-biased when the points are closed, the desired suppression of inverter signal and residual point voltage is achieved.

If the points bounce during normal operation, they discharge C_4 (and the distributor capacitor) almost instantly each time they close. Thus, each time they bounce open, these capacitors must recharge from zero toward the triggering level. With normal bouncing, the points do not stay open long enough for the triggering level to be reached, so the SCR is not triggered. If severe bouncing occurs at very high speeds, the points can stay open long enough to cause triggering of the SCR.

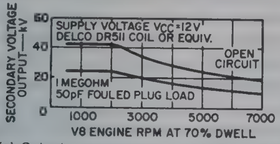
Better filtering is achieved when the automobile distributor capacitor is retained, but satisfactory operation is achieved without this capacitor. With the capacitor left in the distributor, it is possible to switch back to standard ignition by switching the plug shown in Fig. 14.

Commutating the SCR

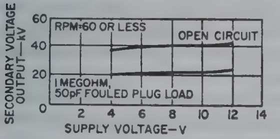
All the parts of the system work together in such a manner as to cause the SCR current to go to zero for a sufficient length of time to cause commutation (turn off). As explained earlier, the current through the primary of the ignition coil is switched from the SCR and into the commutating diode when the primary voltage decreases to zero. From that time on, the diode keeps the coil current clamped out of the SCR. The SCR then conducts only the small current that results from the energy stored in the inverter transformer. When the points close again, the inverter restarts and, as explained previously, the rectifying diode D_2 is reverse-biased during the time the collector current of transistor Q_1 builds back up to the switching level. No current then flows in the SCR, and the SCR is allowed to turn off. Fig. 18 shows that the current is zero for about 2.5 milliseconds before anode voltage is reapplied at a rate of 1.5 volts per microsecond. A worst-case SCR commutates in less than 100 microseconds at a temperature of 100°C under these operating conditions.

Performance

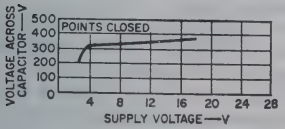
Fig. 21 shows several performance curves for the SCR capacitor-discharge ignition system. Fig. 22 shows the open-circuit output voltage as a function of time, and Fig. 23 shows the output voltage when the load on the secondary consists of a 1-megohm resistor in parallel with a 50-picofarad capacitor.



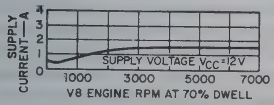
(a) Output voltage as a function of engine rpm at 12 volts for both an open secondary and a fouled-plug load.



(b) Output voltage as a function of battery voltage at cranking speeds for both an open secondary and a fouled-plug load.



(c) Regulation curve showing peak capacitor (and SCR) voltage as a function of battery voltage.

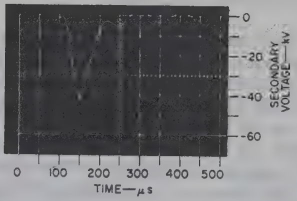


(d) Battery drain as a function of engine rpm at a battery voltage of 12 volts.

92CS–21818

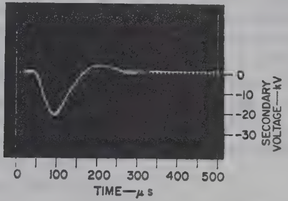
Fig. 21 – Performance of capacitive-discharge ignition circuit.

Figs. 24 and 25 show the secondary voltage under sparking conditions. Arc duration, as shown in Fig. 24 is 600 microseconds (single polarity) under wide-gap conditions. The narrower-gap conditions shown in Fig. 25 result in an arc duration of 200 microseconds.



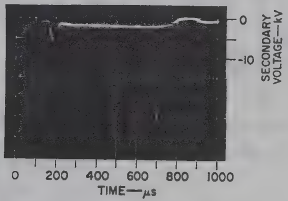
92CS–21819

Fig. 22 – Open-circuit voltage (standard ignition coil, Delco D511 or equivalent; 2000 r/min; V_{CC} = 12 V).



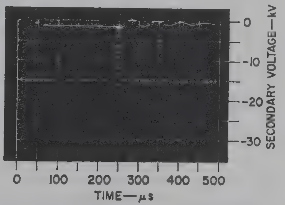
92CS–21820

Fig. 23 – Output voltage with fouled spark plugs (standard ignition coil, Delco D511 or equivalent; 50-pf load in parallel with 1-megohm resistance; 2000 r/min; V_{CC} = 12 V).



92CS–21821

Fig. 24 – Output voltage showing duration of spark arc (standard ignition coil, Delco D511 or equivalent; 2000 r/min; V_{CC} = 12 V).



92CS–21822

Fig. 25 – Output voltage with spark gap shortened (standard ignition coil, Delco D511 or equivalent; 2000 r/min; V_{CC} = 12 V).

Mounting Considerations

The SCR ignition circuit must be protected from moisture. Heat-generating components, however, should not be enclosed in noncirculating atmosphere. Still air has a thermal-resistance 12,000 times that of copper, and generation of heat in this high thermal resistance could cause the inside ambient temperature to rise above the specified limits. All components subject to high temperature rise (marked in Fig. 14 with a small circle) should be thermally connected to a low-thermal-resistance path to the outside environment. For example, the SCR may be mounted to an aluminum plate on a mica insulating washer. This plate should then be fastened to the inside of the chassis wall that provides the thermal path to the outside environment. The resistors and diodes which require a heat sink should be attached to the chassis with a thermally conductive epoxy.

IGNITERS

The previously described CD systems are intended for use in internal combustion engines in which the timing of ignition is an important part of the circuit design. A different application area in which virtually no timing requirements are necessary is the line-charged igniter.

An igniter is used in place of the conventional pilot light in gas-operated equipment and appliances. Some oil-burner applications will also accept a CD igniter as a direct replacement or with a minimum of retro-fitting. A primary advantage to the use of CD igniters with oil burners is the elimination of high-current-carrying contacts which may burn out or otherwise become inoperable with wear and age. When used to replace a pilot light the CD igniter has the obvious advantage of reducing gas consumption, thereby conserving energy. The line-charged igniter has few regulation or charging problems, as it uses the power readily available from the ac line and charges at the line voltage. The gate trigger pulse is derived by using a diac and an RC phase-shift network, as shown in Fig. 26.

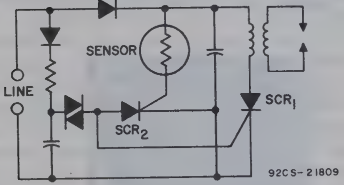


Fig. 26 – Line-charged ignition circuit.

SUMMARY

Inductive-and capacitive-discharge ignition systems have been reviewed, and the advantages and disadvantages of both systems have been discussed. The criteria for SCR selection has been emphasized to provide an insight into reliable and low-cost devices for CD applications. The flywheel-charged system has been described as an economical capacitive-discharge ignition system for small engine applications and marine use. The automotive CD ignition system, although not yet accepted by the automotive industry, has been proven to be reliable as well as beneficial for fuel economy, overall lower maintenance, and improved performance. Line operated CD ignition systems have been shown to be simply constructed, reliable systems with an obvious potential for fuel conservation. In each application discussed, the CD ignition system has demonstrated its ability to meet the ever-increasing demand for greater economy, improved performance, and conservation of energy.

The CD systems described are intended for use as internal-combustion-engine ignitions in which ignition timing is an important part of the circuit design. A different application area in which there are virtually no timing requirements is the line-charged ignition. An igniter may be used in place of the conventional pilot light in gas operated equipment and appliances. In some oil-burner applications, a CD igniter may be installed as a direct replacement, or with a minimum of retro-fitting. A primary advantage to the use of a CD ignition in an oil burner is the elimination of high-current-carrying contacts which may burn out or otherwise become inoperable with wear and age. The CD igniter in pilot-light applications has the obvious advantage of reducing the consumption of gas, thereby conserving energy. The line-charged igniter has few regulation or charging problems, as it uses the power readily available from the ac line and charges at the line voltage.

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